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University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

The influence of community-defined land use plans and *de facto* land use practices on the relative abundance and distribution of large wild mammals in a community-based Wildlife Management Area in Southern Tanzania.

A thesis submitted to University College Cork by Lily Duggan, in fulfilment of the requirements for the degree of Master of Science (Research).

University College Cork.

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Year of Submission of Thesis: 2023.

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Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism and intellectual property.

Acknowledgements

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Abstract

This study investigates the relationship between community-defined land use plans and *de facto* land use practices, and the influence of the latter on the relative abundance and distribution of large wild mammals in a community-based Wildlife Management Area (WMA) adjacent to Nyerere National Park (NNP) in southern Tanzania. The WMA model represents a relatively new approach to community-based conservation in Tanzania, in which local villages set aside part of their land for wildlife conservation and manage that resource collectively, so that their stakeholder communities can leverage economic and social benefits from income-generating activities like tourism. The Ifakara-Lupiro-Mangula (ILUMA) WMA acts as a key buffer zone between the fully domesticated habitats of the villages to the north and west, and Nyerere National Park to the east.

All observed signs of wildlife and human activity were recorded across 32 locations inside ILUMA and in the permanent settlements and national park that border it to the west and east, respectively. For the great majority of wild mammal species, surveys around water bodies within a 2km radius of suitable camping locations proved more sensitive than those along transects between them. The latter transect surveys were only more sensitive for Sable and Spotted Hyena, which are known to routinely commute considerable distances across their home ranges, and for Greater Kudu that seldom drink surface water.

Across much of ILUMA WMA, in areas where agreed land use plans were not adhered to, rampant cattle herding and land clearing for cultivation of rice and other tillage crops were associated with reductions in wildlife richness and biodiversity, as well as overall ecosystem integrity. Many unauthorised human activities were recorded inside ILUMA, such as livestock herding, charcoal burning and agriculture, and, where they occur at a high density, wildlife populations are negatively affected. Although all these activities impact wildlife to some degree, cattle herding had the most

severe negative effect on wildlife (Species Richness, P=0.002, Simpson's Index of Diversity, P=0.0022) and ecosystem integrity (P <<0.0001).

Nevertheless, several well-managed authorised human settlements within the WMA, where fishing is the primary authorised livelihood, support thriving wildlife populations and pristine land cover, so human settlement *per se* was not found to be associated with reductions of any of these composite indices (P≥0.4532), except for the novel subjective natural ecosystem integrity index (P=0.0256). Correspondingly, the best conserved parts of the WMA were those closest to the national park to the east and the fishing villages to the north, where compliance with agreed land use plans is highest. Overall, this study illustrates how well-managed WMAs can host resident local communities undertaking selective and appropriately regulated natural resource extraction activities, while maintaining a rich and diverse local wildlife population and acting as an effective buffer zone between fully domesticated areas of human habitation and pristine environments such as national parks.

Furthermore, this study also developed and evaluated a novel method for synthesizing consensus subjective impressions of the investigators and intuitively expressing them in semi-quantitative format as a readily interpreted *subjective natural ecosystem integrity index* that accounts for all aspects of land use, wildlife and human activities. Crucially, however, this alternative to statistical syntheses of extensive, formally collected survey data is intuitively accessible to all manner of stakeholders, including relevant communities, and should be far better suited to routine programmatic monitoring through participatory approaches.

1. Introduction.

1.1. Community Based Conservation.

Community Based Conservation (CBC) is proposed as an alternative to traditional fortress style conservation and occurs in many countries globally, with varying degrees of success and failures. Two outcomes that are considered successes for CBC are the conservation of natural ecosystems and the many species that live in them, and participation by the local communities, not only in the governance and management of the area, but also in the economic and social benefits (Songorwa, 1999). By providing tangible economic benefits to the local community, through a participatory approach to land use planning and management, the overall idea of CBC is that protected landscapes and natural resources are managed by empowered communities to secure their future on a sustainable basis (Gibson and Marks, 1995). The aim of CBC is to shift the focus of conservation from exclusive state-controlled protection to management through bottom – up, community-based participation and inclusive practices. This shift therefore requires the devolution of natural resource management to local communities (Goldman, 2003). CBC practices across Africa in the 1990s have been criticised for sidelining the community in the process of developing management plans, but still including the community in the policies of conservation (Agrawal and Ribot, 1999, Goldman, 2003). In essence, while the community in theory was included in wildlife conservation policies, devolution of power had not been granted, therefore leading to a lack of governance stakeholdership and management authority at a local level, preventing relevant communities from playing an active role in conservation and the derived socio-economic benefits (Agrawal and Ribot, 1999). The initiative of Wildlife Management Areas (WMAs) in Tanzania, along with other CBC initiatives discussed below, attempt to devolve power, and rectify these management and governance issues.

Local communities can benefit from CBC via consumptive tourism such as regulated trophy hunting (Lindsey *et al.*, 2006) and non-consumptive eco-tourism (Kiss, 2004), both of which aim at strengthening conservation efforts by keeping financial rewards within the local economy, including sustainable livelihoods for community members. Having said that, many CBC initiatives have failed achieve these objectives, and this has been attributed to a lack of business, tourism and marketing skills among the local stakeholder community (Spenceley, 2012). Hence, a mixed picture on the success of CBC has been demonstrated, but with pressure on land use only expected to increase in the coming decades, with a predicted 9.7 billion global citizens by 2050 (Population Division of the United Nations Department of Economic and Social Affairs, 2022), it is vital that conservation that benefits both human and wildlife is robustly established as scalable best-practice models. Africa in particular is expected to see declines in wild mammal habitat of up to 25% by 2050, the primary driver of this being land-use change (Baisero *et al.*, 2020). Combining a solution that both contributes to the local economy sustained with practically sustainable livelihoods, while also conserving wildlife would be considered a win-win solution, this proves difficult in areas where agriculture and other land use practices clash with conservation objectives. The success of CBC has been mixed thus far, and there have been many documented failures in both ecological and economical terms (Salerno *et al.*, 2016). Nevertheless, there have also been some notable success stories for local communities that provide important examples to learn from (Tallis *et al.*, 2008, Brooks, Waylen and Borgerhoff Mulder, 2012).

Conceptualised in Zimbabwe in the 1980's and rolled out in the 1990's, CAMPFIRE (Communal Areas Management Programme for Indigenous Resources) has now been adopted by other African countries such as Botswana, Namibia and Zambia (Balint, 2006). This initiative was pioneered in Mahenye, Zimbabwe. Following on from a mediating session addressing the issue of poaching, at which a compromise was reached (Murphree, 2001), the local people agreed to protect wildlife habitat and cease poaching, in return for 80% of the profits from trophy hunting with a safari operator. Although initially appearing beneficial for the community and local wildlife, conflict arose as the rural district council were not prompt in delivering the community's share of the profits (Murphree, 2001). Based on these early learning experiences, this benefit sharing model was developed further into what is known as the CAMPFIRE initiative today.

For its first decade as a CAMPFIRE project, Mahenye was praised for its diversification of income and its participatory and stable governance (Bond, 2001). Most other CAMPFIRE programmes at the time relied solely on game-hunting, but by diversifying to also include game-viewing tourism, which brought about the establishment of tourist lodges, and by having an accountable committee that was regularly overseen by external reviewers, Mahenye was hailed as a success because the local community accrued tangible benefits (Murphree, 2001). By 2004 the success of this project had deteriorated significantly, leadership was no longer accountable, and the community no longer had confidence in the project. Reasons for this drastic change were due to the traditional chief taking control of the CAMPFIRE committee, preventing new elections to said committee, and not permitting auditing of funds by external sources, despite by-laws to the contrary (Balint, 2006). The cessation of major international funding and reduction in administrative support are also believed to be catalysts to the decline of this quite famous CBC initiative (Balint, 2006). Here it is demonstrated that when an initiative lacks ongoing centralised support, it may struggle to achieve its conservation and poverty-alleviation goals. In the case of Mahenye the collapse of local governance structures, combined with a loss in contact with administrative support from the national CAMPFIRE association, resulted in its demise.

An encouraging picture has been displayed in more recent years by the CAMPFIRE initiatives that have since been established throughout Zimbabwe. Following complaints that districts were not devolving the agreed share of income with the wards and households involved in the programme, an agreement was reached in 2005 for the ward level local government units to be paid directly by the safari tour operators (Taylor, 2009). A 2019 study found that, although donor funding was withdrawn more than a decade previously, households involved in CAMPFIRE initiatives in the south of the country were still benefitting from the programme, albeit at a reduced rate than previously experienced (Tchakatumba *et al.*, 2019). It is suggested that the ongoing sustainability of CAMPFIRE long-term in this particular area would be secured by increasing effective ownership of the programme, by providing tenure security for hunting companies, so that they are committed to the area for an extended period, and improving financial transparency (Tchakatumba *et al.*, 2019).

Another example of CBC or Community Based Natural Resource Management (CBNRM) is highlighted in Namibia. Following an amendment to existing legislation in 1996, the Namibian government created an opportunity for CBNRM by outlining a programme for local community conservancies, whereby the local management of wildlife in a positive manner was envisaged to yield economic development in rural areas and improve local governance. By receiving property rights, rural communities living on communal land were given the right to manage wildlife through conservancies. A local management system for the conservancy is established by members from the community, who create a management plan that incorporates both a wildlife management strategy and a mechanism to share relevant costs and benefits. This CBNRM programme has been praised for its success in achieving both its human and wildlife oriented goals by increasing rural incomes and allowing wildlife populations to recover (Boudreaux and Nelson, 2011).

An innovative component of CBNRM conservancies in Namibia is a system of community monitoring referred to as the *Event Book System*. This system assesses the factors that the community dictates require monitoring such as wildlife populations, infringements of regulations and any economic activities (Stuart-Hill *et al.*, 2005). This simple and practical system has achieved encouraging results, and is considered a reliable system for monitoring wildlife in particular (Stander, 2005, Wenborn *et al.*, 2022). However, as only the aspects of the conservancy that the community deems important are monitored, it is cautioned that an ecosystem-wide view of the area may not be assessed and that an external review may be required in such cases (Stuart-Hill *et al.*, 2005). A 2016 study on 77 conservancies in Namibia found that the economic welfare of local communities was greatly benefitted by tourism, primarily through employment, and that management costs and governance structures were contributed to via revenue from hunting (Naidoo *et al.*, 2016). Overall, the Namibian conservancies model appears to be mostly achieving the goals of CBC, providing a positive example of how authority may be effectively devolved, enabling local communities to make informed decisions on the use of their land. This encouraging example also demonstrates how, when monitored effectively, CBC can simultaneously benefit wildlife populations and improve the economic status of local rural communities.

1.2. Tanzanian Wildlife Legislation.

The current protected area framework for Tanzania was established post World War II, prior to independence, when protected areas were laid out in three separate categories, National Parks (NPs), Game Reserves (GRs) and Game Controlled Areas (GCAs). National parks represent the strictest form of conservation and are a clear and generally successful example of the fortress conservation model, whereby no human extractive activities whatsoever are permitted. Game Reserves and Game Controlled Areas represent less stringent models for government managed conservation areas, in which some restricted exploitation and human activities are permitted. Post independence, the Arusha Manifesto (1961) laid the foundation for the areas protected for wildlife throughout the country and guided all wildlife conservation issues until the country's first wildlife policy was developed in 1998 (United Republic of Tanzania Ministry for Natural Resources and Tourism, 1998) and then later revised in 2007 (United Republic of Tanzania Ministry for Natural Resources and Tourism, 2007).

1.3. Wildlife Management Areas (WMAs).

Although mentioned in the Wildlife policy of 1998, Wildlife Management Areas (WMAs), were only established formally through the *Establishment and Management of Wildlife Management Areas and Benefit Sharing GN* (Government Notice) in The Wildlife Conservation Act of 2005, which was then revised in 2022 (United Republic of Tanzania Ministry for Natural Resources and Tourism, 2022). It is the intention of this form of CBC to "empower local communities to be more involved and to hold more authority over the management of wildlife to promote sustainable biodiversity conservation and rural economic development" (USAID, 2018). Wildlife Management Areas can be established in three locations for the purposes of community-based wildlife conservation; on the periphery of core protected areas, areas which are used by local community members, and areas within village land. In accordance with this act, WMAs should establish administrative mechanisms whereby wildlife conservation is promoted, economic development of the villages is enhanced, and poverty is reduced, and where the distribution of benefits and costs is equitable (United Republic of Tanzania Ministry for Natural Resources and Tourism, 2022).

Each WMA has its own individual set of by-laws and is independently managed. The Minister for Local Government creates model by-laws which are a template example that is first adapted to local needs and preferences, these are taken to the district council and then to the Minister for Natural Resources and Tourism, whose ministry is responsible for ensuring that the local community will benefit from, and are fully informed and consulted, in the WMA establishment process. These model by-laws are then adopted by village authorities and adapted to local needs and preferences by making amendments wherever necessary. Note however, in spite of this flexibility regarding local tailoring, any relevant laws such as the Environmental Management Act (2004), Forest Act (2002), Beekeeping Act (2002), or Fisheries Act (2003) should be conformed to in the adoption of these by-laws. Once the area has been gazetted by the Minister for Natural Resources and Tourism, and fulfilled all legal requirements, it is granted user rights and is assigned as an *Authorised Association* and declared a WMA for community-based conservation. The management of the WMA then have the right to negotiate and sign agreements with potential investors, under the condition that representatives of the district council are present and involved in the negotiation, with the aim of advancing both community development and in wildlife conservation objectives. The WMA is monitored for unauthorised activity by Village Game Scouts (VGS) who are appointed by the WMA management as its equivalent of wildlife rangers. VGS are also responsible for protecting both the natural resources of the area and also people's lives and property from wildlife, in addition to protecting the boundaries of the WMA against encroachment. Every district in the country which has a declared WMA has established a District Natural Resources Advisory Body to advise both the WMA and local government on administration matters for the WMA, which should be consistent with the *General Management Plan* for the WMA. In accordance with this GN in The Wildlife Act (United Republic of Tanzania Ministry for Natural Resources and Tourism, 2022), the *General Management Plan* should be prepared in a participatory manner between the relevant authorities and the local community, which is then approved by the Minister for Natural Resources and Tourism who is responsible for publishing the *General Management Plan* in the Gazette. The *General Management Plans* should be periodically revised and updated.

The general guidelines of the WMA act highlight the importance of using WMAs as a mechanism to effectively implement CBC in Tanzania while also ensuring benefit sharing with the local community. Management of WMAs should be a collaborative effort between the Wildlife Division, District Councils, and other wildlife sector institutions, such as the Tanzania National Parks (TANAPA), National Conservation Area Authority (NCAA) and Tanzania Wildlife Research Institute (TAWIRI).

Currently 19 WMAs are operational in Tanzania, accounting for 7% of the country's total land area, and a further 19 were in the planning stages as of 2018 (Lee and Bond, 2018). Although WMAs were introduced as a model to decentralise control over wildlife areas, there has been some critical commentary regarding the roles played by the government with regards to revenue collection and implementation of conservation enforcement measures in some WMAs (Igoe and Croucher, 2007, Benjaminsen *et al.*, 2013). The picture on the effectiveness of WMAs throughout Tanzania is a mixed one, with conflicting reports from different individual WMAs.

One WMA in particular, Burunge WMA, had documented reports of increased community poverty and discontent with the WMA (Igoe and Croucher, 2007), and unfavourable cost-benefit ratios, as well as a land use plan that was not adequately prepared for a growing demand for grazing (Moyo, Ijumba and Lund, 2016). However, since 2015, VGS training has increased leading to a strengthening of enforcement in Burunge WMA. Since then, wildlife densities inside the WMA have become higher than those outside and woody vegetation inside the WMA has remained dense, indicating an intact ecosystem, and that efforts to reduce timber harvesting are working (Lee, 2018). In 2018, mammal estimated species richness was found to not differ significantly for the majority of species surveyed between Burunge WMA and Tarangire NP (Kiffner *et al.*, 2020) indicating that this WMA provides valuable habitat for wildlife. Higher wildlife densities were reported inside the WMA than outside in village land, and although this may be due to the difference in habitat type and vegetation cover between the two areas, it was suggested that an appropriate location (both the correct habitat types and geographic location - situated in a wildlife corridor between the two national parks) was chosen for this WMA, and that an increased adherence to the land use plan may see Burunge WMA benefit both community and wildlife in the proceeding years. The management committee and VGS of this WMA were also supported in in recent years with the appropriate training and technical assistance, strengthening the capacity of governance. In addition to this, a large ecotourism industry is supported in the area which is part of the popular northern tourist circuit of Tanzania, and Burunge WMA is in close proximity to two popular national parks, Tarangire National Park and Lake Manyara National Park (Lee, 2018), so these circumstances create more revenue generating opportunities for the community going forward than more isolated locations away from the main tourist circuit. A recent study on the attitudes of residents of the villages surrounding Burunge WMA found that 77.5% of people were fully compliant with the regulations and that compliance with the regulations was significantly impacted by community participation in their formation (Tang'are and Mwanyoka, 2023). This encouraging example, illustrates how deficits in management practices and associated deviance from land use plans, can lead to issues in WMAs, however, given the supports discussed and integration into joined-up regional tourism development plans, this model has capacity to support both the livelihoods of locals and meet conservation objectives. One such regional tourism development plan is the REGROW programme developed for southern Tanzania, which aims to improve the limited tourism infrastructure such as roads and airstrips in the south of the country, making conservation areas more accessible, and strengthen CBC approaches in the region.

In theory the WMA concept offers the promise of a win – win situation for all parties involved. However, in practice there has been a somewhat negative picture portrayed in literature of WMAs in Tanzania, with power struggles (Kicheleri *et al.*, 2018), a stunt in community development due to restrictive land use plans (Moyo, Ijumba and Lund, 2016), and crop damage by wildlife (Mwakaje, 2008) reported as substantive issues. The importance of learning to use land in a way that benefits local community development while also supporting wildlife and conservation efforts, is vital given growing land use pressure globally. As was discussed in the Burunge WMA example, when correct supports are given and the land use plan adhered to, WMAs may be an important participatory option for resolving the inherent conflict between rural socio-economic development and wildlife conservation priorities. Therefore, this study will examine variations in adherence to land use plans, and associated consequences for the natural ecosystem across a relatively new WMA in Southern Tanzania, namely ILUMA WMA.

1.4. Ifakara Lupiro Mangula Wildlife Management Area - ILUMA WMA.

In May of 2015 ILUMA was issued user rights and declared the 19th WMA in Tanzania (United Republic of Tanzania Ministry of Natural Resources and Tourism, 2015). 14 villages from both the Ulanga and Kilombero districts with a total of more than 80, 000 residents are included as stakeholder communities in this WMA (United Republic of Tanzania Ministry of Natural Resources and Tourism, 2015). ILUMA is a community-based conservation and rural development governance body and is defined as “An institution founded by 14 villages in the divisions of Ifakara, Lupiro and Mangula with the aim of becoming a wildlife management area for the purposes of benefitting from wildlife resources, especially tourist hunting and other forms of tourism and investment”. The communities of these 14 villages agreed to pool together parts of their land and manage it collectively under the WMA model. The by-laws in place in ILUMA both align it with other WMAs in Tanzania and outline land use practices specific for the area. The by-laws encompass the entire area of ILUMA and are in accordance with proclamation number 206, June 2012 and are explained explicitly in a 2016 document shared with the community (District Authorities, 2016). As outlined in this document, every resident of the villages has the responsibility to protect ILUMA WMA by providing information on any type of unauthorised activity in the WMA such as poaching or charcoal burning, and preventing and extinguishing fires that may occur in the area.

Alongside the WMA, ILUMA as an institution consists of three zones where extractive activities are permitted, with different resource utilisation functions assigned to them: a wetland zone, a local hunting zone and a zone for tourist hunting. These consumption zones are intended as a means for the local communities to benefit economically from the institution of ILUMA. Recommended uses in the wetland zone include photographic tourism and fishing for the local market using local licences. Three authorised local cooperative fishing communities are established and located inside the wetland zone of ILUMA; *Mikeregembe*, *Mdalangwila* and *Funga*. In the management plan these are referred to as *Beach Management Units* (BMUs). Monitored fishing is permitted in these areas under licence and the ILUMA by-laws include regulations on how these settlements are maintained. For example, construction of a permanent residence in these locations is not permitted so all structures must be temporary in nature using only natural materials like mud, sticks and thatch rather than bricks and iron sheets. The residents of these areas are allowed to collect dry wood for such purposes as cooking and drying fish but are not permitted to harvest any live trees. Charcoal burning is also not permitted. The hunting zones, both tourist and local, require a wildlife hunting permit, which is issued by the Department of Wildlife. The permit should, in principle, be allocated after a wildlife assessment has taken place so that it does not adversely affect the conservation of wildlife. Activities not permitted inside ILUMA WMA include entering into the area without permission, housebuilding, cultivation, or keeping livestock. Clearing trees, harvesting wood, and burning charcoal as well as harvesting honey and setting fires are not permitted, nor is fishing except with licence in the designated BMUs. Village Game Scouts (VGS) are responsible for the day-to-day protection of the natural resources available within the boundaries of ILUMA, by carrying out inspection patrols on a regular basis and collaborate with other legal bodies, such as TANAPA, The Wildlife Division, the police, and the district government in operations to prevent poaching.

At face value, these guidelines and management mechanisms appear ideal for protecting both the livelihoods of the local people from the 14 villages and conserving wildlife. However, anecdotal evidence and concerns voiced at a stakeholder meeting held in September 2022 suggested that the governance structure was struggling and that the land use plans formally agreed upon were not being adhered to (Tarimo, Unpublished). A change in leadership from village elected representatives had not been carried out since before the designation of user rights to ILUMA and the residents of the villages had not been kept informed of the status of the WMA (Tarimo, Unpublished). The aim of this study was therefore to evaluate how well the formally agreed land use plans compared with the *de facto* land use practices ongoing across the area of ILUMA WMA, and to assess how well the area is working as a WMA from a wildlife conservation viewpoint.

The overall goal of this study was to provide a comprehensive description of how the relative abundance and distribution of wild mammals was influenced by both community defined land-use plans and *de facto* land use practices across ILUMA WMA.

2. Methodology.

2.1 Field Methodology.

2.1.1 Study Area.

The study area is located both inside ILUMA Wildlife Management Area (ILUMA WMA), and outside it in the villages immediately surrounding its border to the west, and in Nyerere National Park (NNP) to the east. ILUMA WMA is located in the Kilombero Valley [08°40’S 36°10’E] in both the Kilombero and Ulanga districts of the Morogoro region in Southern Tanzania (Figure 1). Covering an area of over 7, 000km^2 the Kilombero Valley is the largest lowland freshwater wetland in East Africa. ILUMA WMA is nested within this valley and spans 509km^2 in area (United Republic of Tanzania Ministry for Natural Resources and Tourism, 2023). Located in south-eastern Tanzania, NNP is Africa’s largest national park spanning 30,893 km^2 (‘Nyerere National Park’, 2023). It was designated national park status in 2019, having previously formed part of the Selous game reserve. ILUMA’s northern boundary is demarcated by the Kilombero river, while areas to the south, west and north contain expanses of agricultural land and villages. Almost 85% of ILUMA’s area lies within the Kilombero Valley RAMSAR Site. ILUMA acts as a buffer zone for NNP and includes zones for tourist hunting and local hunting in addition to a wetland conservation zone. Establishment began in 2011 and user rights were declared in 2015, making ILUMA the 19th WMA in Tanzania (United Republic of Tanzania Ministry of Natural Resources and Tourism, 2015). Land from 14 villages is encompassed by ILUMA (Daconto *et al.*, 2018), and its cover consists of miombo woodlands, dense groundwater forest, riparian forest, open grasslands and wetlands. The climate of the region is tropical with distinct seasons. The season of reasonably consistent heavy rainfall occurs between March and May each year, June through to October generally experience very little to no rainfall, and a short season of more sporadic rainfall occurs between November and February. Annual average rainfall in the Kilombero valley varies between 1, 200 -1, 400mm (Mombo *et al.*, 2011), and temperatures are highest from December to March.

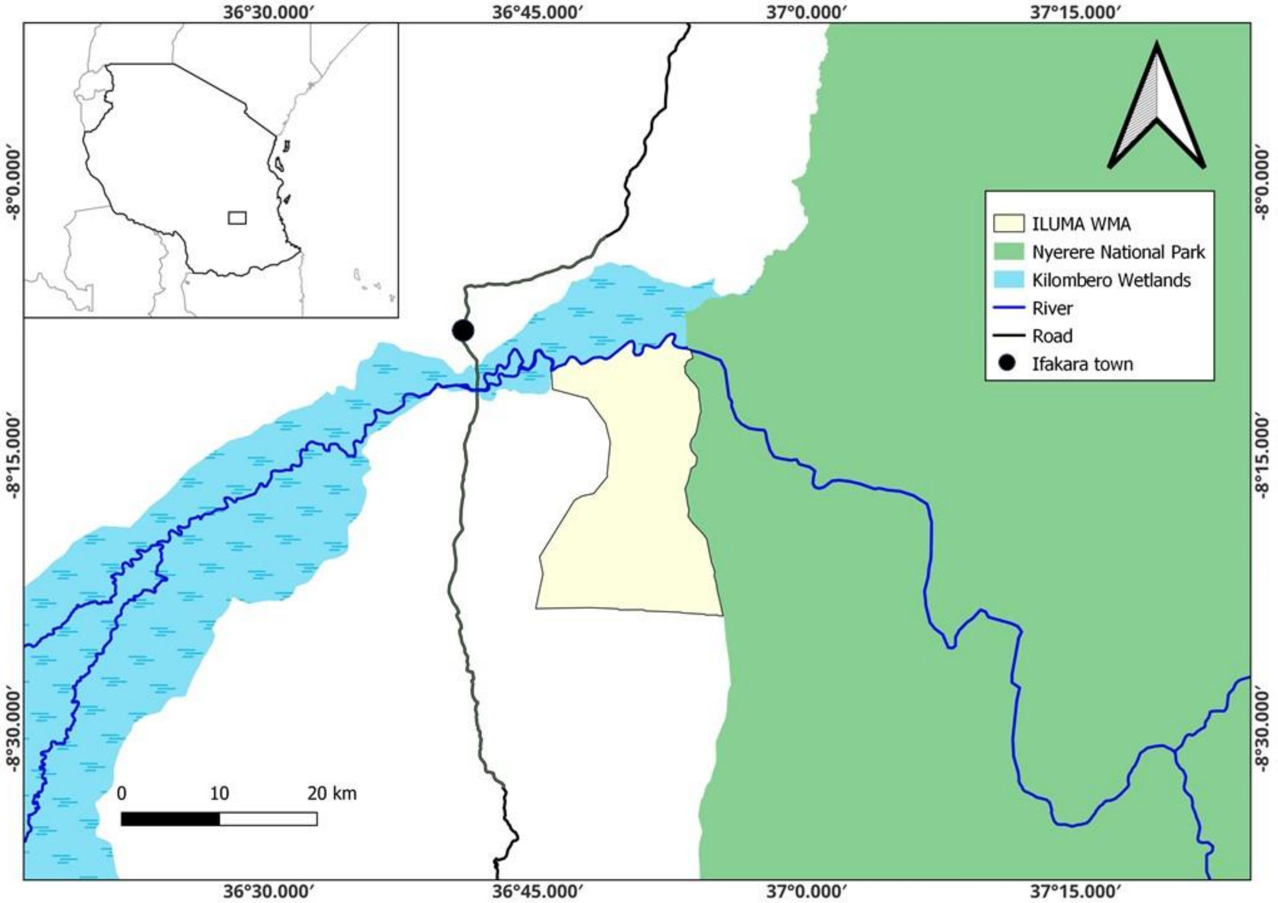

Figure 1. Map displaying the survey area in a national context. Inserted is a map of Tanzania and the enlarged area shows the part of ILUMA Wildlife Management Area south of the Kilombero river where most of the surveys were carried out in the context of the nearby Nyerere National Park, Kilombero wetlands and Ifakara town.

2.1.2. Sampling Design.

The survey area (Figure 2) (Table 1) consisted of 32 distinct locations, referred to as camps, assigned numbers from 1 – 32. These were distributed throughout the study area: 22 inside ILUMA's borders, 6 outside in the domesticated areas close to villages and 4 camps in Nyerere National Park. It should be noted that this study was nested within a larger project related to malaria vector mosquito ecology (Kavishe *et al.,* forthcoming, Walsh *et al.,* forthcoming) whose objectives determined the majority of the sample locations. The logistical requirements of this study therefore had to be adapted to fit within the data collection requirements of the larger project. Some constraints that were considered when choosing survey sites include suitable camp location for the objectives of Kavishe *et al*., (forthcoming) and Walsh *et al.,* (forthcoming) and year-round access to surface water where malaria vector mosquitoes can breed. This surface water also provided the team with water for drinking, cooking, and bathing. Locations were usually associated with shade and firewood, within a day's walk to camp 1, which acted as a base camp and where mosquitoes were transported to (Kavishe *et al.,* forthcoming) and supplies of food and equipment were transferred to and from. See Table 1 for details of each camp's specific location and habitat type.

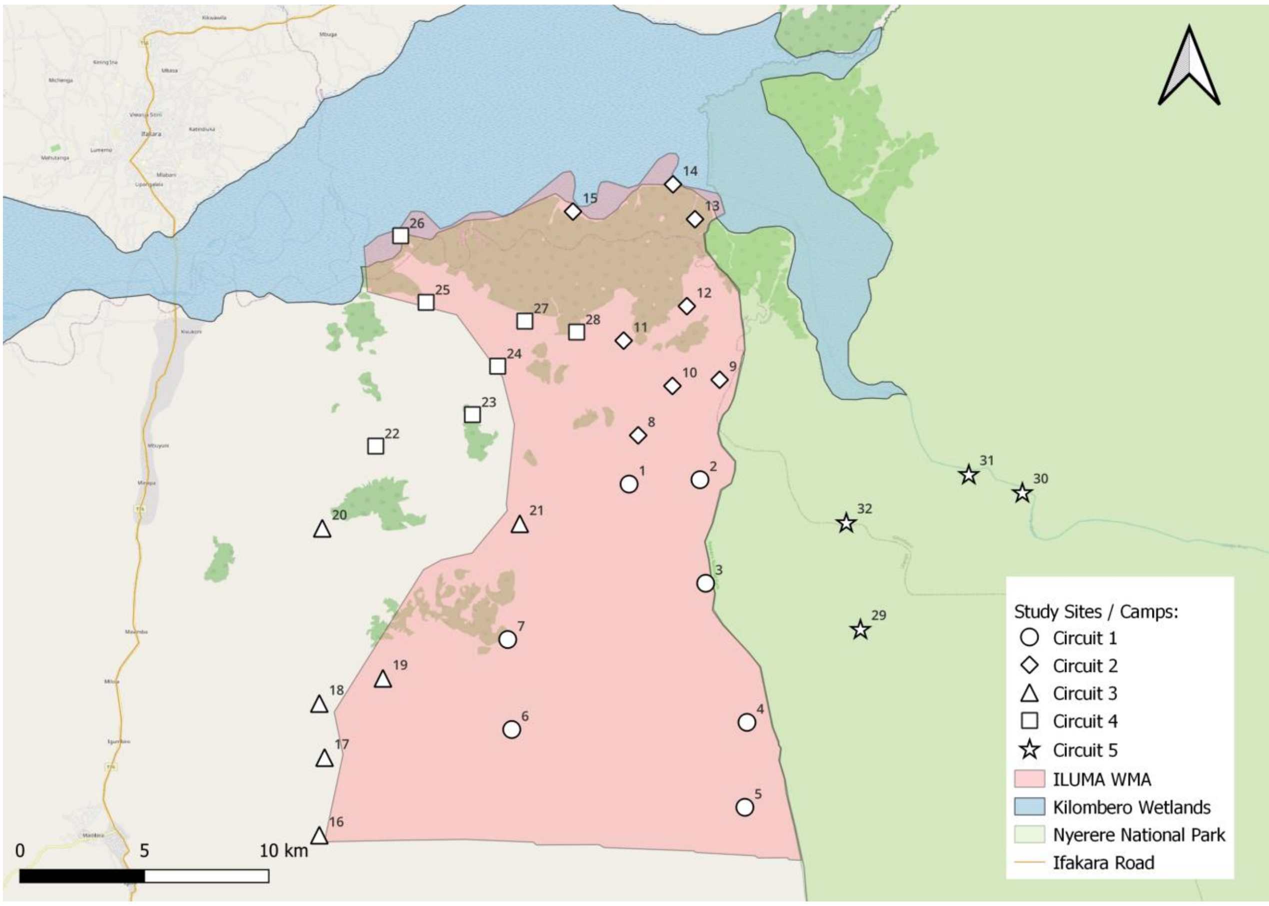

Figure 2. Map displaying the study area sampled during fieldwork. Included are the 32 study sites/camps and the boundaries of ILUMA WMA and Nyerere National Park.

Table 1. The number, name, location, coordinates, and habitat type of each camp is described. Also included here is the circuit assigned to the camp and the number of times it was surveyed.

Camp Number	**Camp Name**	**Circuit**	**Camp Location**	**Camp Coordinates**	**No. of Times Surveyed**	**Habitat Type**

1	Msakamba	Southeast	Inside ILUMA WMA	-8.25981S, 36.85936E	3	Recovering miombo woodland along a small seasonal stream bed.
2	Msiba wa Deo	Southeast	Inside ILUMA WMA	-8.25821S, 36.88524E	3	Intact miombo woodland along a small seasonal stream bed.
3	Bwawa la Nyati	Southeast	Inside ILUMA WMA	-8.29598S, 36.88732E	3	Intact miombo woodland surrounding a large waterhole.
4	Bwawa la Nandete	Southeast	Inside ILUMA WMA	-8.3467S, 36.9024E	3	Degraded miombo woodland surrounding a large waterhole.
5	Korongo la Bundu	Southeast	Inside ILUMA WMA	-8.37768S, 36.90163E	3	Degraded miombo woodland along a small seasonal stream bed.
6	Bwawa la Namamba	Southeast	Inside ILUMA WMA	-8.34931S, 36.81653E	3	Degraded miombo woodland surrounding a large waterhole.
7	Bwawa la Chakacheni	Southeast	Inside ILUMA WMA	-8.31649S, 36.81507E	3	Degraded miombo woodland surrounding a large waterhole.
8	Bwawa la Njuju	Northeast	Inside ILUMA WMA	-8.24204S, 36.86268E	3	Intact miombo woodland surrounding a large waterhole.
9	Bwawa la Chamvi	Northeast	Inside ILUMA WMA	-8.22176S, 36.89241E	2	Intact miombo woodland surrounding a large waterhole.
10	Bwawa la Miembeni	Northeast	Inside ILUMA WMA	-8.22401S, 36.87518E	1	Mostly intact miombo woodland surrounding a waterhole.
11	Kisima cha Seba	Northeast	Inside ILUMA WMA	-8.20749S, 36.85738E	2	Intact miombo woodland adjacent to a small waterhole.
12	Bwawa la Maya	Northeast	Inside ILUMA WMA	-8.19492S, 36.88045E	3	Transition zone between miombo woodland and groundwater forest surrounding a large waterhole.
13	Bwawa la Mrope	Northeast	Inside ILUMA WMA	-8.16321S, 36.88341E	2	Dense groundwater forest surrounding a large waterhole.
14	Mikeregembe	Northeast	Inside ILUMA WMA	-8.15048S, 36.87539E	3	Authorised fishing camp on the banks of the Kilombero river,

						open but bordering groundwater forest.
15	Mdalangwila	Northeast	Inside ILUMA WMA	-8.16041S, 36.83887E	3	Authorised fishing camp on the banks of the Kilombero river, open but bordering groundwater forest.
16	Bwawa la Muamachi	Southwest	Village outside western boundary of ILUMA WMA	-8.38785S, 36.74629E	3	Village outside the conservation area surrounding a large waterhole.
17	Tuliza Moyo	Southwest	Village outside western boundary of ILUMA WMA	-8.35954S, 36.74821E	3	Village outside the conservation area along a small seasonal stream bed.
18	Mavimba Porini	Southwest	Village outside western boundary of ILUMA WMA	-8.33982S, 36.74628E	3	Village outside the conservation area along a large river and surrounding a large waterhole.
19	Bwawa la Selesussi	Southwest	Inside ILUMA WMA	-8.33064S, 36.76951E	3	Degraded miombo woodland surrounding a large waterhole.
20	Makingi	Southwest	Village outside western boundary of ILUMA WMA	-8.27593S, 36.74737E	3	Village outside the conservation area along a small seasonal stream bed.
21	Bwawa la Mpunga	Southwest	Inside ILUMA WMA	-8.27426S, 36.81946E	3	Highly degraded miombo woodland surrounding a large waterhole.
22	Kisaki	Northwest	Village outside western boundary of ILUMA WMA	-8.24595S, 36.7669E	2	Largest human settlement, at the base of a large hill adjacent to a spring and large waterhole.
23	Uwanja wa Ndege	Northwest	Village outside western boundary of ILUMA WMA	-8.23448S, 36.80218E	2	Human settlement along a small seasonal river.
24	Bwawa la Mkwajuni	Northwest	Inside ILUMA WMA	-8.21681S, 36.81141E	2	Intact miombo woodland surrounding a

						degraded large waterhole.
25	Bwawa la Mamba Luhogi	Northwest	Inside ILUMA WMA	-8.19352S, 36.78527E	2	Intact miombo woodland surrounding a highly degraded large waterhole.
26	Funga	Northwest	Inside ILUMA WMA	-8.16924S, 36.776E	2	Authorised fishing camp on the banks of the Kilombero river, open but bordering intact groundwater forest.
27	Bwawa la Mlenda	Northwest	Inside ILUMA WMA	-8.20037S, 36.82132E	2	Intact miombo woodland surrounding a large waterhole.
28	Bwawa la Semka	Northwest	Inside ILUMA WMA	-8.20436S, 36.84023E	2	Largely intact groundwater forest surrounding a large waterhole.
29	Bwawa la Simba	Nyerere	Nyerere NP (East of ILUMA WMA)	-8.31298S, 36.94381E	1	Transition zone of mixed miombo woodland and acacia savanna surrounding a waterhole.
30	Kiboko Zanzibar	Nyerere	Nyerere NP (East of ILUMA WMA)	-8.26313S, 37.00293E	1	Open acacia savanna on the banks of the Kilombero river.
31	Zanzibar	Nyerere	Nyerere NP (East of ILUMA WMA)	-8.2565S, 36.98337E	1	Transition zone of mixed miombo woodland and acacia savanna on the banks of the Kilombero river.
32	Bwawa la Moto	Nyerere	Nyerere NP (East of ILUMA WMA)	-8.2741S, 36.93866E	1	Transition zone of mixed miombo woodland and acacia savanna surrounding a waterhole.

The 22 ILUMA camps were dispersed throughout the entire WMA with the aim of representing each quadrant of ILUMA approximately equally, while also staying within the confines of logistic feasibility. The geographic distribution of the camps within ILUMA was planned to include degraded areas with lots of human encroachment, areas of both open and dense miombo woodland, dense

groundwater forests and authorised human settlements, specifically fishing camps, on the banks of the Kilombero river. Figures 3, 4, 5 and 6 illustrate the difference between these camp types.

There was a substantial difference not only between the different camps surveyed, but also between the same camps during different seasons, as the level of surface water changes dramatically throughout the calendar year. (See figures 4 and 5 for example). Additional study sites outside of ILUMA WMA were included so that those inside could be compared and contrasted with completely unprotected, domesticated land. The inclusion of NNP camps was decided upon once round 2 of data collection was completed to address the objectives of Kavishe *et al.* (forthcoming), and Walsh *et al.* (forthcoming) which required the collection of mosquitoes from completely pristine areas as far away from people and livestock as possible. Nevertheless, the inclusion of these camps benefits this study immensely as they add an additional, more rigorous conservation model to the sampled area. The comparison between domesticated areas, WMA's and national parks can be examined following the gradient of ecological protection level survey sites within this study area.

Figure 3. Image taken at camp 2, set in an intact miombo woodland. Note the combination of mature trees and rapidly growing saplings. This camp is located in the east of ILUMA, close to the border of NNP.

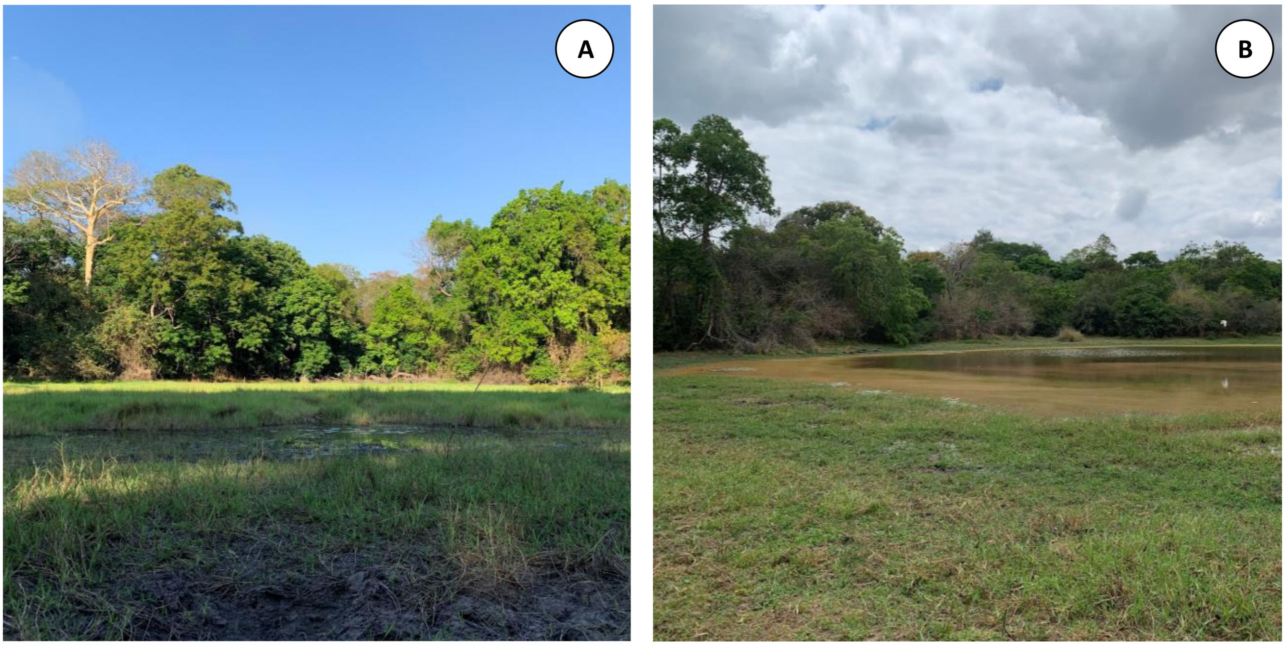

Figure 4. Images taken at camp 13, where a waterhole (Bwawa) is surrounded by intact dense groundwater forest. Image B displays a larger area of surface water than image A, illustrating how the level of available surface water changes throughout the year at specific locations.

Figure 5: Image taken at camp 9 displays a parched large waterhole- *Bwawa* -within a typical area of miombo woodland with surrounding vegetation having sparse leaf cover. This image demonstrates the dramatic variation in level of surface water availability throughout a calendar year and a specific ground type that preserves signs of human activity or wildlife well during the dry season.

Figure 6: Image A displaying a highly encroached area sampled during a camp radial survey, with evidence of deforestation, conversion of land for tillage agriculture and human settlement. Image B taken at camp 14, displaying a typical authorised fishing camp, with evidence of human settlement in the foreground on the banks of the Kilombero river. Beyond the river is low-lying land creating the natural floodplain. Note the contrast in level of land clearance between these two settlements.

2.1.3. Data Collection Form and Data Dictionary Key.

A number of reviews on large mammal wildlife monitoring were considered prior to finalisation od data collection methods, as these illustrate how different methods are best suited to different study requirements, such as; (Sanderson, 1966; Burton et al., 2015; Wang et al., 2019). Unfortunately, formal quantitative surveys of wild animal abundance, activity or biodiversity, or indeed broader assessments of the functionality of the complex natural ecosystems they live in, are often laborious and expensive to apply in low-income contexts (Danielsen *et al.,* 2005; Poulsen and Luanglath 2005; Evans *et al.,* 2018; Kusters *et al.,* 2018; Mandeville *et al.,* 2023). Furthermore, meaningful statistical analysis of the data obtained requires considerable time and expertise, which often lies beyond the technical capabilities and budgets that such small-to-medium scale community-based programmes can sustain outside of time-limited projects (Danielsen *et al.,* 2005; Poulsen and Luanglath 2005; Setty *et al.,* 2008; Mandeville *et al.,* 2023). In order to accurately record observations for this study, a data dictionary key indicating how each observation should be recorded, and a data collection form were developed.

Preliminary surveys carried out in October and November of 2021, combined with local knowledge from our field guides and discussed with them using illustrations from a reference text book (Kingdon, 2015) enabled a comprehensive list of species found in the area to be compiled (Table 2). The combination of different possible ways in which an activity or entity could be observed was also noted and distinguished (Table 3), such as direct sightings, tracks or spoor for example. The age of each observation also was important to note, and it was decided to divide the age of an observation into three categories: active, recent or old (See Table 4 for the specifics of these categories per entity or activity). The usefulness of the species list and observation categories were evaluated during a number of field trials using both the data collection key and forms. These trials were carried out in late 2021 to test the effectiveness, practicality, and precision of these data recording methods and make adjustments as required in advance of formal data collection for inclusion in the analyses. The result of this procedural pilot exercise was the data collection key presented in Table 4, which was used throughout the entire course of this study, in conjunction with the data collection sheet (Figure 7).

Table 2. Complete list of all wild herbivores, wild carnivores, wild primates and prosimians and wild rodents sampled in this study.

Wild Herbivores.	**Wild Carnivores.**	**Wild Primates and Prosimians.**
Bohor Reedbuck (*Redunca redunca wardi*)	Lion (*Panthera leo*)	Lesser Bush Baby (*Galago senegalensis*)
Common Waterbuck (*Kobus ellipsiprymnus ellipsiprymnus*)	Leopard (*Panthera pardus*)	Greater Bush Baby (*Galago crassicaudatus*)
Puku (*Kobus vardoni*)	African Wild Cat (*Felis libyca*)	Yellow Baboon (*Papio cynocephalus cynocephalus*)
Bushbuck (*Tragelaphus scriptus*)	African Civet (*Civettictis civetta*)	Vervet Monkey (*Cercopithecus aethiops*)
Common Eland (*Taurotragus oryx*)	Genet (*Genetta spp.*)	Blue Monkey (*Cercopithecus mitis*)
Greater Kudu (*Tragelaphus strepsiceros*)	Spotted Hyena (*Crocuta Crocuta*)	
Hartebeest (*Alcelaphus buselaphus*)	African Wild Dog (*Lycaon pictus*)	**Wild Rodents.**
Wildebeest (*Coonochaetes taurinus*)	Side-Striped Jackal (*Canis adustus*)	Porcupine (*Hystrix cristata*)
Sable (*Hippotragus niger*)	Slender Mongoose (*Herpestes sanguineus*)	Giant Cane Rat (*Thryonomys swinderainus*)
Warthog (*Phacochoerus aethiopicus*)	Banded Mongoose (*Mungos mungo*)	
Bushpig (*Potamochoerus porcus*)	Water Mongoose (*Atilax paludinosus*)	**Macroscelidea.**
Hippopotamus (*Hippopotamus amphibius*)	White-Tailed Mongoose (*Ichneumia albicauda*)	Sengi (*Petrodromus tetradactylus*)
Elephant (*Loxodonta Africana*)	Honey Badger (*Mellivora capensis*)	
African Buffalo (*Syncerus caffer*)	African Clawless Otter (*Aonyx capensis*)	**Tubulidentata.**
Plains Zebra (*Equus burchelli*)		Aardvark (*Orycteropus afer*)
Suni (*Neotragus moschatus*)		
Common Duiker (*Sylvicapra grimmia*)		

Natal Red Duiker (*Cephalophus natalensis*)		
Impala (*Aepyceros melampus*)		
Ugogo Dikdik (*Madoqua kirkii thomasi*)		
Sharpe's Grysbok (*Raphicerus sharpei*)		

Table 3. Criteria defining terms used in data dictionary key.

Direct sighting: Live animal or human actually seen by one or more members of the field team.
Tracks: Prints (animal or human) seen by the data recorder on the ground on the immediate path being followed.
Spoor: Faecal excrement seen by the data recorder on the on the immediate path being followed.
Other signs: Any sign of animal activity that undoubtedly links to a specific species (elephant pulling bark from a tree or water mongoose cracking shells for example).

Table 4. Data collection key devised during preliminary study in October and November 2021 and used throughout the course of the field study to inform accurate and consistent recording of data.

Entity or Activity Observed (EAO)	**Observation Category (OC)**	**Additional Observation Attributes (AOA)**	**Observation Count or Class (OCC)**
1X "As you go" instances of specific human land and/or natural resources usages.			
11: Livestock Herding			**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
12: Charcoal Burning			**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
13: Timber Harvesting			**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
14: Fishing			**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
15: Hunting			**1**: Active, **2**: Recent, 3: Old, **9**: Not determined or recorded
16: Human Settlement		**1,2,3…10** structures [n], 11-20 structures **[20],** 21-50 structures **[50],** >50 structures **[100]**, not determined or recorded **[9]**	**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
17: Water Body			**1**: Stagnant waterbody, **2**: Puddle(s) outside a seasonal streambed, **3:** Puddle(s) outside a seasonal streambed **4**: Flowing stream, **5**: Flooded valley
18: Human dug well			**1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
19: Meat Poaching			**1:** Active**, 2:** Recent, **3:** Old**, 9:** Not determined or recorded
2X: "As you go" sightings, tracks and signs of humans and animals.			
21: Humans	1: Direct sighting, 2: Tracks, 3: Spoor, **4**: Other signs (Explain in notes)	**1**: ILUMA personnel, **2**: NNP Rangers, **3**: Hunting company staff, **4**: Other authorized personnel from ILUMA and other authorized institutions, **5**: Community legal presence inside conservation area, **6**: Community legal presence outside the conservation area, **7**: Charcoal transport, **8**: Timber harvesting, **9**: Timber transport, **10**: Fish harvesting, **11**: Fish transport, **12**: Community illegal presence inside the conservation area, **13:** Charcoal burner.	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
22: Livestock and work animals	**1**: Direct sighting, **2**: Tracks, **3**: Spoor, **4**: Other	**1**: Cattle, **2**: Goats, **3**: Sheep, **4**: Rooster, **5**: Chicken, **6**: Dog	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3:** Old, **9**: Not determined or recorded
23: Wild Herbivores	**1**: Direct sighting, **2**: Tracks, **3**:	1X: Reduncini (**11**: Reedbuck, **12**: Waterbuck, **13**: Puku), 2X: Spiral Horned Antelopes (**21**: Bushbuck, **22**: Eland, **23**: Greater Kudu) 3X:	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**:

	Spoor, **4**: Other signs (Explain in notes)	Alcephalines (**31**: Hartebeest, **32**: Wildebeest), 4X: Hippotragini (**41**: Sable Antelope), 5X: Suidae (**51**: Warthog, **52**: Bushpig), 6X Semi-Plantigrade (**61**: Hippo, **62**: Elephant), 7X: Bovinae (**71**: African Buffalo), 8X: Equidae (**81**: Plains Zebra), 9X: Neotragini (**91**: Suni), 10X: Cephalophini (**101**: Common Duiker, **102**: Red Duiker), 11X: Aepycerotini (**111**: Common Impala), 12X: Madoquini (**121**: Dikdik), 13X: Raphicerini (**131**: Sharpe's Grysbok)	Recent, **3**: Old, **9**: Not determined or recorded
24: Wild Carnivores	1: Direct sighting, 2: Tracks, 3: Spoor, 4: Other signs (Explain in notes)	1X: Pantherinae (**11**: Lion, **12**: Leopard), 2X: Felidae (**21**: African wild cat), 3X: Viverridae (**31**: African Civet, **32**: Cape Genet), 4X: Hyaenidae (**41**: Spotted Hyena), 5X: Canidae (**51**: African wild dog, **52**: Side - Striped Jackal), 6X: Herpestidae (**61**: Slender Mongoose, **62**: Banded Mongoose **63:** Water Mongoose, **64:** White Tailed Mongoose), 7X: Mustelids (**71**: Honey Badger), 8X Lutrinae (**81**: African Clawless Otter)	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
25: Wild Primates and Prosimians	**1**: Direct sighting, **2**: Tracks, **3**: Spoor, **4**: Other	**1**: Lesser Galago, **2**: Greater Galago, **3**: Baboon, **4**: Vervet, **5**: Blue Monkey	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
26: Rodents	**1**: Direct sighting, **2**: Tracks, **3**: Spoor, **4**: Other	1: Hystricidae (**11**: Porcupine, **12**: Giant Cane Rat)	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
27: Macroscelidea	**1**: Direct sighting, **2**: Tracks, **3**: Spoor, **4**: Other	1: Rhynchoninae (**11:** Sengei)	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
28: Tubulidentata	**1**: Direct sighting, **2**: Tracks, **3**: Spoor, **4**: Other	1: Orycteropodidae (**11:** Aardvark)	Distance (m) from track for direct observations, or age for tracks and signs: **1**: Active, **2**: Recent, **3**: Old, **9**: Not determined or recorded
3X: Summary impressions of land cover attributes averaged over entire segment.			
31: Rice farming			**1**: 0%, **2**: 1 - 25%, **3**: 26 - 50%, **4**: 51 - 75%, **5**: 76 - 100%
32: Other Tillage Crops			**1**: 0%, **2**: 1 - 25%, **3**: 26 - 50%, **4**: 51 - 75%, **5**: 76 - 100%
33: Grass and forb height			**1:** <1ft, **2:** 1 - 3ft, **3:** 3 -6ft, **4:** 6ft+
34: Visibility of obstruction by Shrubs, Bushes and Trees			**1**: 0%, **2**: 1 - 25%, **3**: 26 - 50%, **4**: 51 - 75%, **5**: 76 - 100%
35: Ground Type			**1**: Hard & Dry, **2:** Sand, **3:** Damp Soil, **4**: Mud, **5:** Water, **6:** Rock, **7:** Gravel & Pebbles

Form Type (FT): Land Use Observations (LUO)				**Date (DT):** / /	**GPS Identifier (GID):**	**Form Serial Number (SEN):**
Transect Start Camp Number (TSCNO):				**Transect Start Camp Name or Description (TSCND):**		
Transect Segment Number (TSN):					**Transect Start GPS Way Point Number (TSGWPN):**	
Transect Segment Page Number (TSPN):					**Transect End GPS Way Point Number (TEGWPN):**	
Form Row (FR)	**Entity or Activity Observed (EAO)**	**Observation Category (OC)**	**Additional observation attributes (AOA)**	**Observation count or class (OCC)**	**Observation Notes (ONO):** Specify details that add qualitative insight or enable post-hoc classification	
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Figure 7. Data collection sheet developed during preliminary investigation in October and November 2021 and used for all data collection in both transect segment surveys and camp radial surveys throughout the course of the study.

2.2. Survey types.

2.2.1. Day to day activities of a typical data collection period.

Each survey round, of which there were three, was spilt into multiple circuits of roughly 2 weeks in duration. Each such circuit encompassed two overnight stays at each of the camps in one of the circuits outlined in Figure 2 and Table 1, plus hikes on foot between said camps. Circuits began and ended at camp 1, *Msakamba* (See Figure 8), where a permanent fenced camp acted as a control base of operations. Round one consisted of three circuits, round two of four circuits and round three of five, the latter including an extra circuit of the four additional camps inside NNP. During each of these two-week tours of a single circuit as they were referred to, between six and eight camps were visited, although the final circuit of the third round of data collection included only the camps inside NNP. One radial survey and one transect survey was associated with each camp, with the former carried out within a two-kilometre radius of the camp and the latter conducted the following day enroute from that camp to the next. The field team consisted of three primary investigators carrying out the survey methods described here for the land use survey, larval surveys described in Walsh *et al*., (forthcoming) and nightly mosquito collections described in Kavishe *et al*., (forthcoming). Eight members of the VGS, comprised the remainder of the field team, they guided the team through the WMA, helped in carrying supplies of equipment, and were vital in choosing optimum locations for collecting water and pitching tents. Two VGS members were responsible for transporting mosquitoes and supplies of food and batteries etc. between *Msakamba* and the location of the mobile field team (See Kavishe *et al.,* (forthcoming) for further detail.

Day 1 of a typical two-week data collection segment would involve ensuring all equipment and food supplies were packed. Travel to the first camp of that circuit was also undertaken on day 1. For the purposes of the larger study (Kavishe *et al.,* 2023), two nights were spent at each camp. The day spent travelling to each was called the *moving day* during which a transect survey was undertaken (see section *2.2.2*), following which a mobile camp was established and mosquitoes were collected in the evening and early the following morning. After mosquitoes were collected and taken care of in the early morning, a radial survey around the camp was carried out in the morning and early afternoon of that full day spent at that camp (see section *2.2.3*). The following morning marked the start of another *moving day* which started with the final adult mosquito collections, before the camp was packed up and the team moved to the next location (Figure 2, Table 1), undertaking a transect segment survey along the way to the next camp.

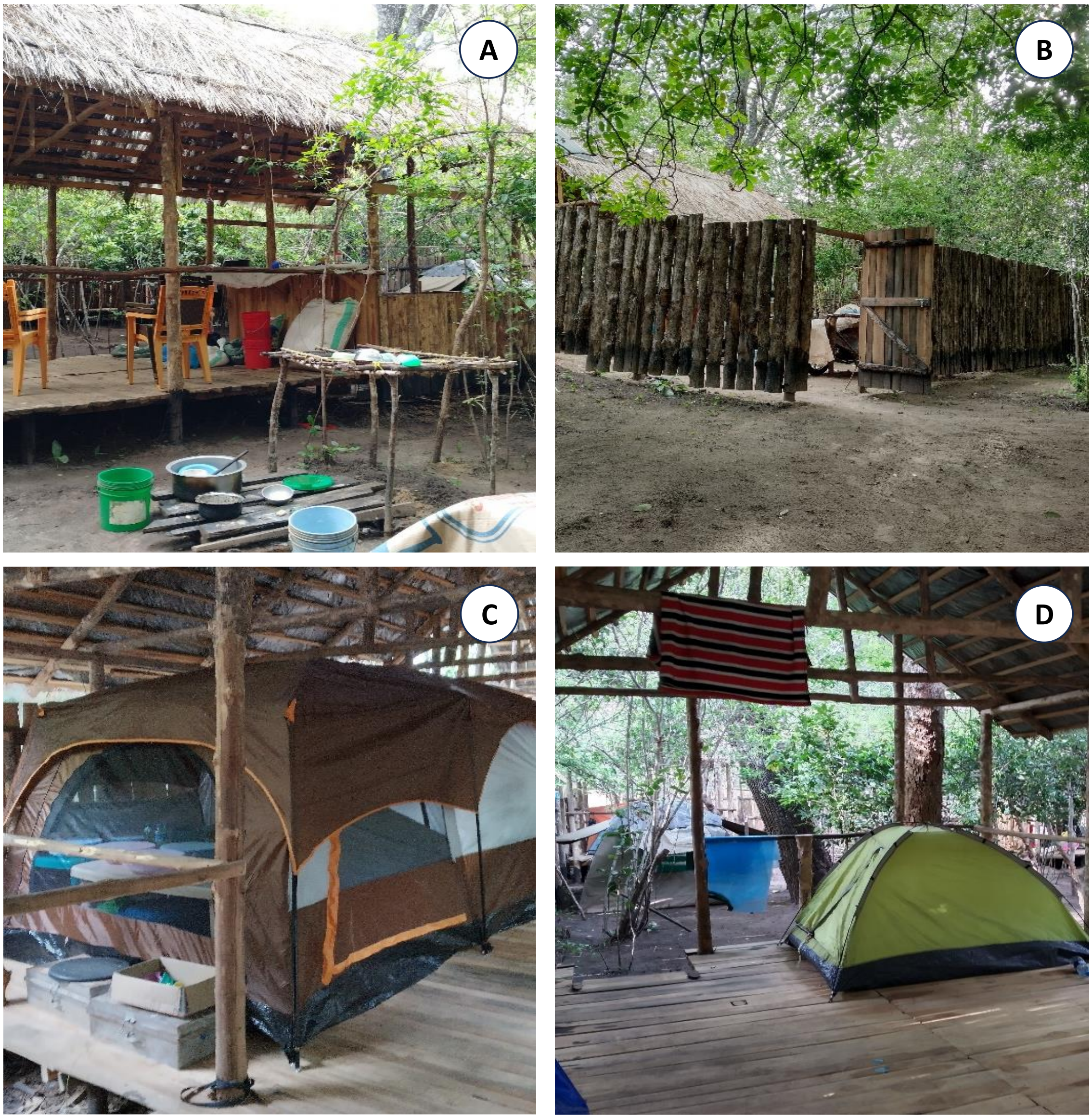

Figure 8. Images depicting Msakamba (camp 1) which acted as a logistical headquarters for field operations. Image A shows the shelter provided from heavy rain and intense sunshine and also facilities for storing and cooking food. Image B illustrates the fence that encompasses the area. Image C is of one of the mosquito insectaries (Kavishe *et al*., forthcoming). Image D shows a raised platform and shelter where tents were pitched, which was especially useful in the rainy season.

Immediately after the survey, either once a new camp was reached (transect segment survey), or the same camp was returned to (radial survey), all recorded data was entered into a digital database using Microsoft Excel® (2019). By possessing both physical and digital versions of the data recorded, it was ensured that any damage due to weather or accidents did not render the data lost. By entering the data on the same day as collection, it also helped to detect and correct any mistakes in the coding of species during data collection while the day's activities were fresh in the mind of the investigator, and also it was the most time efficient, as entering all the data once the circuit had been completed could take up to an entire day. GPS coordinates were noted manually during data entry each day and the data was uploaded from the GPS device (Garmin eTrex10) and stored in an Excel® workbook at the end of each quadrant.

The journeys between all camps, during which transect surveys were carried out, were travelled by foot with all required equipment and supplies. Occasionally a 4 – wheel drive vehicle would drop the field team to the first camp of a circuit or collect us from the last, otherwise the distance back to camp 1 was again travelled by foot. Camp 1, *Msakamba,* acted as our base camp, with a fence, shelters, platforms, chairs and solar power electricity supply, from where we could travel out of the WMA for a few days break between circuits or spend a few days before undertaking the next circuit.

2.2.2. Transect Surveys.

Transect surveys were undertaken every second day on the so-called *moving day*. The starting point of this survey was the camp that was being departed from. Time of departure was noted, usually between 07:30 and 08:30. Using a Garmin® eTrex GPS, a distance of 500m was measured along the route. Each 500m of distance was walked during which all relevant observations were recorded and referred to as a transect segment. A maximum of ten transect segments were completed each day, as, during the field trials, this was determined to be the maximum distance that full concentration on data collection could be maintained, given all the challenging weather and underfoot conditions and the weight of equipment and personal effects carried by the investigator, as well as the relentlessness of the field procedures including the nightly mosquito catches also carried out. A new data recording sheet (Figure 7) was used for each segment. If the distance between camps was less than 5km, 500m segments were recorded up to the point that the new camp was reached. If the distance between camps was greater than 5km, ten 500m segments were completed, the survey stopped, and the team completed the distance uninterrupted. The GPS coordinates at the beginning and end points of each transect segment were recorded.

Also, at the end of each segment an overall impression of land cover attributes (See Table 4, Section 3X) was recorded. Similarly, a subjective estimated proportions of land covered with rice cultivation and with other tillage agriculture was recorded. For example, Figure 9 (panels A and B) illustrates a transect segment survey that was designated to the 76-100% category of rice agriculture as it occupied the entire transect segment. Both panels A and B of Figure 9, although in very different stages of seasonal weather and cultivation, were assigned the same score here as depending on round, the presentation of this type of agriculture differs significantly. Figure 9C shows the typical manner in which agriculture of other tillage crops was detected. The overall impression of land cover was recorded according to Section 3X of Table 4, was the only section of the key that was mandatory to be filled out for each transect segment at its end point. Also, an impression of how much visibility was blocked vertically by the height of grasses and forbs, and horizontally by the density of tree and shrub cover were recorded. Lastly the ground type was also recorded, the categories are outlined in Table 4 (Section 3X), and include sand, damp soil and gravel/pebbles.

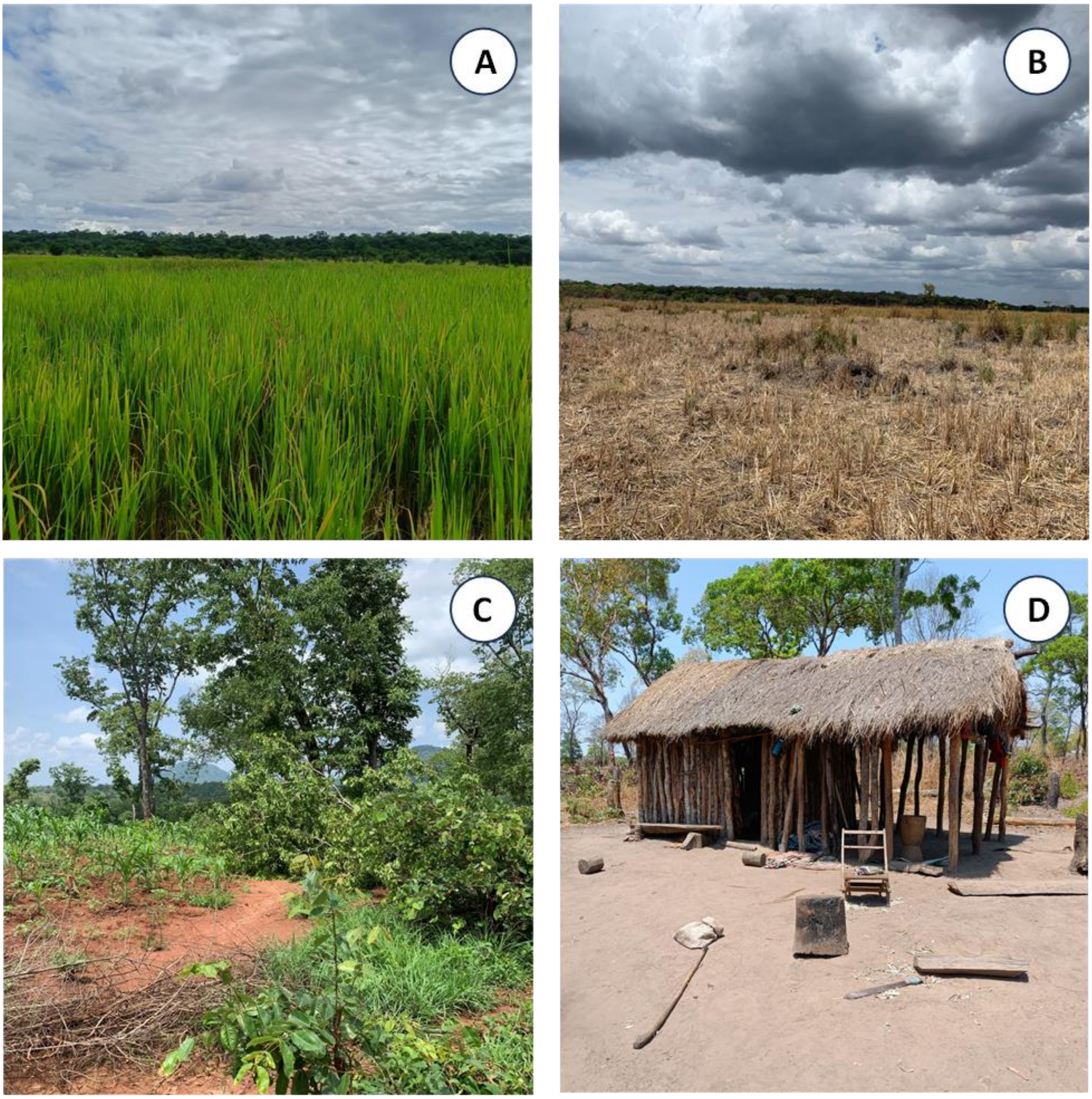

Figure 9. Images showing how the impression of land cover for rice farming and other tillage agriculture was recorded. Both images A and B display rice agriculture in different stages. The rice in image A is still growing and is lush green. Image B depicts how this same area looked once the rice had been harvested and the dry season began. Image C demonstrates the other forms of tillage farming detected in ILUMA. Here, maize is beginning to grow in deforested and cleared land. The mature trees in the background depict what the area looked prior to agricultural use. Image D illustrates an unauthorised human settlement inside ILUMA. Structures similar to the one depicted usually accompany agricultural activity, such as that shown in image C. Note also, the level of land clearance in the area surrounding the settlement.

Any animal or human activities encountered along the route were recorded following the categories on the key (Table 3). Each observation was recorded on a new numbered row of the form and each new form was unambiguously identified by its own unique combination of serial number, transect segment number and transect segment page number. Figure 10 illustrates examples of the kinds of tracks, spoor and other signs observed by the investigator when spoor, print and other signs detections were made. It is important to note the difference in ground types of these two images. Damp sand is the perfect medium for detecting prints but is not a very common type of ground cover in ILUMA. The observer had to be extremely vigilant when recording data, as factors such as leaf litter could make some signs hard to detect. The VGS proved invaluable in highlighting inconspicuous signs of wildlife and had vast knowledge of wildlife prints and spoor and were called on to help identify the species where determination of a sign was difficult. It was also very important for the rest of the field team to be observant of where they were walking, as signs could easily be obscured or destroyed by trampling on them, therefore, the primary investigator for these surveys was always positioned second in the line, just behind the lead VGS member who navigated the path. The field team also had to refrain from unnecessary conversations as noises could disturb wildlife or unauthorised humans in the surrounding environment and cause them to flee before they could be directly observed.

Human settlement (Figure 9D) was recorded in the number of structures present. Activities such as charcoal burning, timber harvesting, unauthorised fishing and meat poaching were typically detected in the manner they are depicted in Figure 11. Occasionally an unforeseen human activity that had not been included in the key was detected (Figure 12). In such case it was recorded as unauthorised community presence within the WMA and extra explanatory notes were provided.

Figure 10. Images illustrating different ways in which livestock and/or human recordings (direct sighting, tracks, spoor or other signs) were detected. Panel A shows a direct sighting of cattle. Panel B shows an observation rarely detected, namely fresh lion prints on damp sand which resulted in perfectly clear tracks and an unambiguous identification of the animal and age of the tracks. Contrasting this, panel C shows one of the most frequently recorded detections throughout the entire survey - Hartebeest spoor, 3 days old. Panel D displays an example of “other signs”, here broken shells and a stick used as an anvil by water mongoose to obtain snails and shellfish is shown. This sign was frequently recorded throughout the study.

Figure 11. Images showing unauthorised activities recorded during data collection in the field. Image A shows active charcoal burning. Timber from felled trees is placed in a pile, covered in soil to create a low oxygen environment, and then set on fire. Image B displays an area that is undergoing active deforestation. The trees that have been felled would be used for charcoal production or for the construction of human settlements or occasionally timber to be sold commercially. Image C shows evidence of unauthorised fishing. A dam made of soil and mud was constructed across a large stream. This blocks the flow of water and prevents fish from moving past that point. Also used is a bed net, to catch fish as they approach the dam. Image D displays the items seized from a meat poacher during a routine patrol. Bicycles are an efficient mode of transport through the WMA for both people and goods. Supplies to last for up to a week and equipment used in the capture of wildlife were in the sack pictured behind the bicycle.

Figure 12. Images A and B show an unauthorised human activity taking place in ILUMA WMA that was not anticipated to be detected and is an example of an unusual activity. Here, a form of homemade alcohol is being produced through distillation with grain cultivated illegally inside the conservation area. As with fish poaching, a river is blocked which causes knock-on issues for the aquatic ecosystem. Pollution of the watercourse is evident here.

2.2.3. Radial Surveys.

Similar surveys within a defined day of each camp occurred on the alternate days to the transect surveys, on the days the team stayed at a camp and the larval study was undertaken (Walsh *et al.*, forthcoming). These surveys were centred around the fringes of waterbodies and designed to follow the procedures of the accompanying team surveying malaria vector mosquito larvae, so the chosen direction taken, and waterbodies surveyed was determined by the data collection requirements detailed in Walsh *et al.,* (forthcoming). The waterbodies surveyed included seasonal streambeds and the pools of water within them, puddles and pools outside of streambeds, natural (ephemeral) stagnant waterholes, pools of water in rice fields and rivers. The camp acted as a central anchor point for the survey. Radial surveys coordinates were recorded. The geographic extent of these *radial surveys* was limited to a two-kilometre radius in any direction from the camp although in practice the team always purposely went in the direction of the most waterbodies. The area covered between the camp and the first waterbody was surveyed and data was recorded, then the waterbody would be circumnavigated, and this was repeated between and around further waterbodies. Camp radial surveys were not segmented, and a new data collection sheet was used only when the previous one was full. If four hours had passed prior to the 2km distance being reached, the survey was ended at that point. Four hours was determined as the cut off point for concentration and accurate data recording due to conditions, weather and underfoot as well as the physical exertion involved in descending and ascending steep channels of seasonal stream beds to inspect tracks and signs at the bottom of them. In some cases, 2km radii in multiple directions was completed and all the waterbodies within the two-kilometre limit were surveyed within the four-hour time frame, so the survey was then ended. Distance and time were measured using a Garmin® eTrex10 GPS device. Again, variables capturing several subjective synthetic impressions of land cover attributes over the course of the survey in section 3X of the key was recorded at the end of the survey similarly to transect surveys. Note however, that for camp radial surveys this was completed only once, at the end of the survey, to give an overall impression of the entire 2km radius surrounding the camp. The recording of human activities and wildlife was accomplished using the exact same procedures outlined for transect surveys in the preceding section.

2.2.4. Overall geographic and temporal sampling frame.

Data were collected in three distinct rounds. Round 1: from 21st January to 16th March 2022. Round 2: from 22nd March to 25th May 2022. Round 3: from 25th August to 29th November 2022. Rounds one and two occurred during the wet season and round 3 during the dry season. Not every camp was visited in each round due to circumstances such as physical inaccessibility during the rains or lack of accessible surface or groundwater for cooking and drinking at the end of the dry season. Nevertheless, round 1 surveyed 20 camps, 17 inside ILUMA and 3 outside. Round 2 surveyed all 22 camps inside ILUMA and 6 camps outside, and round three surveyed 18 camps inside ILUMA, 6 outside and 4 in Nyerere National Park. The exact number of rounds each individual camp was visited is displayed in Table 1.

2.3. Data Management.

2.3.1. Data Cleaning and Recoding.

Management was undertaken in the RStudio® version 2023.03.0+386 interface using pre-loaded, base packages (*Base, Graphics, grDevices, methods, stats, utils*) and *reshape2,* Microsoft Excel® (2019) and Microsoft Access® (2016).

The data in all columns were verified by examining two-way frequency tables in RStudio, whereby date was used to break down frequencies for every other variable, allowing the range of values to be inspected for plausibility based on common sense, experience and recent recollections of the actual observations and recording process used in the field. Any value that looked to be incorrect was highlighted and checked against the hard copies of the raw data. All instances in which this occurred were trivial typing errors during data entry, so retaining the paper hard copies allowed these mistakes to be quickly rectified. Data entry immediately after collection in the field helped keep these trivial errors to a minimum.

Once all of the data entry mistakes were corrected, a new variable *OCCrecode* was added to the dataset to create a slightly modified version of the variable recording *Observation Count or Class* (*OCC*). Any row in which a direct observation was recorded was noted and its *OCC* value was recoded to a value of 1. This category was used to record the distance from the animal at the time of observation, but only in the case of a direct observation. This would have caused issues for subsequent analyses by preventing directly observed species from being grouped together regardless of distance, thus the recode to give all such rows of data a common value in a new variable to be used in the linking stage. All other values for the *OCC* variable were unaltered and carried over to the recode variable as is.

A similar situation occurred with *Additional Observation Attributes* (*AOA*) variable within human settlement was recorded. An *AOArecode* variable was created to allow a single value (10) to represent all settlements with ten or fewer structures, while every other *AOA* value remained unchanged.

Furthermore, a final additional variable was added: *NumberObserved*, which was assigned a value of 1 for every row as each individual observation was recorded on its own line, so that subsequent aggregation steps could be used to yield total numbers of observations for each combination of the *EAO, OC, AOA, OCC* variables. The last step in the cleaning and recoding of the raw data involved changing all of the blank cells with missing values to numerically coded zeros.

Once all of the raw data was cleaned, the GPS coordinates were cross checked across rounds. The majority of the camps were visited three times throughout the three rounds of the study, so the GPS points collected during each round were compared by overlaying them on a map, to ensure no inconsistencies due to any loss of satellite connectivity at the time of recording the location. Once this was complete, a full list of confirmed coordinates for each camp was finalised.

2.3.2. Processing data into a form suitable for analyses.

Overall, subsequent data processing consisted of three basic steps:1) linking to data templates including zero values, including all possible combinations of date (DT) and transect segment number (TSN) variables so that all the different possible combinations of detecting each activity and entity that were recorded over any given transect survey segment or camp radial survey could be accounted for as not having been detected rather than merely being missing data. 2) Aggregation to yield total numbers of detection observations for each of the possible combinations of values of all the variables. 3) Restructuring from a vertical format in which all these possible variable-by-value combinations were represented by separate entries or rows, into a horizontal format in which they were represented by separate variables or columns.

2.3.2.1. Creating a template data table listing all possible combinations of values for the different types of observations.

A list of all possible combinations of possible values for all the variables described above was created by linking those lists into a single flat data table using Access®. Each species could have been recorded as one of thirteen possible combinations of values for *Observation Category* (*OC*) and *Observation*

Count or Class (*OCC*). A *join* variable was added to both of these separate tables of possible values for each of the two variables so that they could be linked to each other. This linked flat data table was saved as an Excel® file.

2.3.2.2. Creating a template data table listing the dates and unique identities of all completed transect survey segments and camp radial surveys.

In order to create a list of *Date* (*DT*) and *Transect Segment Number* (*TSN*) (0 = radial survey, 1 to 10 = transect survey segment) combinations that uniquely identify distinct survey units of sampling, the clean raw dataset was aggregated in RStudio® by the new *NumberObserved* variable previously added, using the following break variables; *Transect Segment Number* (*TSN*) and *Date* (*DT*) using the summary function *sum*. This slightly aggregated form of the data was exported as an Excel® flat file. A *join* variable was added in Excel® to enable linking with the complimentary data template file from section *2.3.2.1.*

2.3.2.3. Creating a master template listing all the possible combinations of variable values detailed above.

Using Access®, the templates created in sections *2.3.2.1* and *2.3.2.2* were linked together using the *join* variables of these two tables as the common linking variable. This produced a master template listing every possible type of observation for each and every activity or species on each date that any survey was carried out as well as the identity of every camp radial survey or transect segment survey completed. This linked flat table was saved as a standalone document in Access®.

2.3.2.4. Linking the master data template with unprocessed data.

The fully cleaned data set with all the survey observations was then imported to Access® and linked with the master template, using all variables that contained the same information in both tables as the means to distinguish separate types of observations during different radial surveys or transect survey segments namely *Date* (*DT*), *Form Serial Number* (*SEN*), *Camp Number* (*TSCNO*), *Transect Segment Number* (*TSN*), *Entity or Activity Observed* (*EAO*), *Observation Category* (*OC*), recoded version of

*Additional Observation Attribute*s (*AOA*) and recoded version of *Observation Count or Class* (*OCC*). The resulting flat file was exported into Excel® and then converted to a csv file, before being imported into *RStudio*® for further processing from vertical to horizontal format prior to data analysis.

2.3.2.5. Restructuring from a vertical to a horizontal data table format.

Using the paste function in *RStudio*®, a new variable (*EAOOCAOAOCC*) was added to the dataset. This variable is a merged combination of all the values recorded for the *EAO, OC, AOA* and *OCC* variables per observation. As described below, rather than reading across four different variables to determine what specific type of observation was detailed across a given line of data, this combination variable provides a succinct summary. This variable was also vital in the following aggregation and restructuring steps.

2.3.2.6. Total values for each activity or entity observed.

In order to uniquely identify each recording, but also compress the number of rows to shorten the data set and make use of the *NumberObserved* column to get totals per radial survey or transect segment, aggregation was carried out, using the *aggregate* function of *RStudio*®. *Date* (*DT*), *Camp Number* (*TSCNO*), *Transect Segment Number* (*TSN*), *EAO, OC, AOA, OCC* were the break variables and the summary function used was *sum*.

Finally, this dataset was flipped using the *dcast* function from *reshape2* package in RStudio, from vertical to horizontal format, so that each column represents a unique EAOOCAOAOCC combination, and the values within that column represent the total number of times that particular combination was recorded in a given radial survey or transect survey segment. *Date* (*DT*), *Camp Number* (*TSCNO*) and *Transect Segment Number* (*TSN*) were retained as the variable used to distinguish separate lines of data in the restructured horizontal format. This data provides the total frequencies for each combination of the EAO, OC, AOA and OCC, on every given survey and could then be used for subsequent analyses. This form of the data was used for analysis in section *2.4.1.*

2.3.2.7. Mean values for each activity or entity observed per camp.

For analyses comparing the characteristics of different variables in camp locations, the mean values for each observation type per camp were calculated to account and normalise the differences in the number of times each camp was visited. To obtain mean values, the data described in section *2.3.2.4* was aggregated in *RStudio*® following the same procedure as outlined in section *2.3.2.5*, but once this aggregation step was complete, the data was further aggregated using *Camp Number* (*TSCNO*), *Transect Segment Number* (*TSN*), *EAO, OC, AOA* and *OCC*, as the break variables and using the *mean* function instead of *sum*. This produced a simple arithmetic average value for each EAOOCAOAOCC combination value per camp.

This dataset was again restructured from vertical to horizontal format using the *dcast* function from the *reshape2* package in *RStudio*®. Now camp number and transect segment number along with every combination value for EAOOCAOAOCC became the variable or column names, and the mean number of times each observation was observed populated the cells. Finally, only data collected during camp radial surveys was used for location-specific analyses, therefore this data set was subjected to the *subset* function to produce a dataset that contained 32 rows (one for each camp), with the mean values of numbers observed reported in each unique EAOOCAOAOCC combination value column. This form of the dataset was used for analyses in sections *2.4.4., 2.4.5., 2.4.6.,* and *2.5.1.*

2.4. Statistical Analyses.

2.4.1. Calculating total observation frequencies and mean frequencies for each entity, activity, or land cover attributes.

2.4.1.1. Total frequencies of humans, livestock, wild herbivores, wild carnivores, wild primates and prosimians, and wild rodents.

Data analysed in in this section was managed according to section *2.3.2.6* and analysis was undertaken in *RStudio*® using packages *stats, lme4*, *MASS, nlme* and *glmmPQL*.

All indicators of wild animals (herbivores, carnivores, primates, prosimians and rodents), livestock and humans were evaluated, with camp radial surveys and transect segment surveys analysed separately. Total frequencies for each discrete variable for both camp radial surveys and transect survey segments were both calculated in frequency tables. While they were analysed separately, mean frequencies and 95% CIs for both camp radial surveys and transect segment surveys were both calculated by fitting generalised linear mixed models (GLMM) with no intercept and a random effect for camp number, the only independent variable, using penalised quasi -likelihood (PQL) method using the *glmmPQL* package, assuming Poisson distribution for the dependent variable, namely the number of times that observation type was recorded. The final models for both camp radial survey and transect survey segment data excluded data relating to values for variables that were never observed, as the 95% CIs for the negligible means were inestimable and resulted in very poor model fits and/or failure of the models to converge. The values produced by this analysis are detailed in Appendix 1.

2.4.1.2. Total and mean frequencies of human activities

All entities or activities relating to the presence of humans were evaluated, and again camp radial surveys and transect segment surveys were analysed separately. Total frequencies for each discrete and categorical variable for both camp radial surveys and transect survey segments were calculated and presented in frequency tables.

For each variable that was recorded as a discrete number of observations, mean frequency and 95% confidence interval were calculated for camp radial data by fitting a GLMM using the *lme4* package and *glmer* function with camp number and round number as random effects and a negative binomial distribution specified for the dependent variable. This distribution was chosen as it yielded consistently lower Akaike Information Criterion (AIC) scores than equivalent GLMMs with Poisson distribution.

Using the *glmmPQL* package, mean frequencies with confidence intervals for transect survey segment data were calculated by fitting GLMMs with no intercept and camp number as the sole independent variable and a random effect for round using the PQL method and assuming a negative binomial distribution for the dependent variable. The initial theta values, required for fitting the distribution of the dependent variable for this model, were obtained by fitting a GLMM with a negative binomial distribution, specifying camp number and round number as random effects with no fixed effects and no intercept. As per the analysis in section *2.4.1.1*, the final models for both camp radial (*glmer*) and transect segment data (*glmmPQL*) excluded data relating to values for categorical variables that were never observed, as the 95% CIs for the negligible means were inestimable and resulted in very poor model fits and/or prevented the models from converging. The values produced in this analysis are displayed in Appendix 2.

2.4.2. Comparison of survey methods for wild mammals: transect surveys versus camp radial surveys.

The number of detections for each wild mammal species observed on all transect segment surveys was divided by the total number of detections of that species over both survey types (transect segment and camp radial surveys) to obtain a proportion of all detections that occurred during transect surveys. Using the *stats* package, mean frequencies and associated 95% confidence intervals for the proportion of all detections for each wild mammal species that occurred on transect surveys were calculated by fitting a generalised linear model with the *glm* function in Rstudio®, specifying a binomial distribution and logit link function for the dependent variable and no intercept. The GLM was weighted by the total number of all wildlife species observed. For species in which too few detections occurred to fit a GLM, detections only occurred in camp radial surveys. The probability of having occurred by random chance was calculated directly as $P = 0.5^{n-1}$ where n is the number of detections made. Unfortunately, n did not reach a value of 7, the minimum required to test for significance at the 0.05 level in the case of only a few species results of this analysis were represented in a bar plot in Excel®, which is displayed in Figure 34.

2.4.3. Rationale for focusing exclusively on camp radial survey data for subsequent assessments of biodiversity and natural ecosystem integrity.

There are two primary reasons for focusing only on camp radial surveys analyses, using data processed as described in section *2.3.2.7* only. Firstly, the results of analyses undertaken in section *2.4.2* show that camp radial surveys detected significantly more occurrences of most wild species than transect segment surveys. Also, further analyses of indicators of ecological intactness and species diversity were better served by this method because it yields a much larger number of detected species overall.

Secondly, the analyses from this point forward aimed to independently quantify the ecological status of each location and compare with other locations across the study area. By analysing data collected within a 2km radius of each camp, all of which are at least 2.5km from the neighbouring camp, a reasonable degree of spatial separation and statistical independence may be assured. In contrast, individual segments within transect surveys are completely continuous with each other and together often stretch all the way from one camp to the next, so they are essentially guaranteed to exhibit strong spatial autocorrelation that renders standard statistical methods assuming independence invalid. Autocorrelation could address these issues to exploit the full potential of these data, to do so would go beyond the scope of this master's degree project. Data collected during transect survey segments portrays the gradient of wildlife from one camp to the next and is at times equidistant between two camps.

2.4.4. Diversity indices.

All analyses in in this section used data processed as described in section *2.3.2.7.*

2.4.4.1. Ecological stratification based on K-medoids cluster analysis.

Cluster analysis was undertaken using the *cluster, dplyr* and *Rtsne* packages, plus *ggplot2* and *scales* for graphing. Cluster analysis identifies groups or trends of similar objects in a dataset. It is not influenced by *a priori* notions of which samples should be designated to which cluster (Kassambara, 2015). The result is the formation of groups with high similarity of variables and is beneficial in exposing the structure of communities (Pritchard and Anderson, 1971). Cluster analysis was chosen as the primary statistical tool as it would cluster together camps with similarities and separate them from those that were different. This gave a solid basic foundation to build from with subsequent analyses. Cluster analysis was performed to test whether the camp locations visited could be statistically resolved into ecologically distinct data that could be interpreted in terms of their status of protection and geographic location (e.g., in villages outside ILUMA WMA, inside ILUMA WMA, and inside NNP).

The silhouette method was used to determine the optimum number of clusters using the *cluster* package. The output suggested two clusters as the optimum, followed by four and then eight (Figure 13). For completeness, cluster analysis was undertaken on each of these suggested numbers of clusters. Four clusters produced two large clusters, while the other two clusters contained just one camp each. Eight clusters produced very small clusters of just a handful of camps where it was very difficult to establish a readily interpreted trend in clustering or an intuitive interpretation of what each cluster represented. It was therefore decided that two clusters were not just the best fit to the data (Figure 13), but also the most practically useful because the two clusters clearly represented degraded versus pristine classes (Figure 35). Plots of Gower dissimilarities were created using *Rtsne* and *ggplot2* packages to reveal clear patterns of clustering (see section *3.4.1.*).

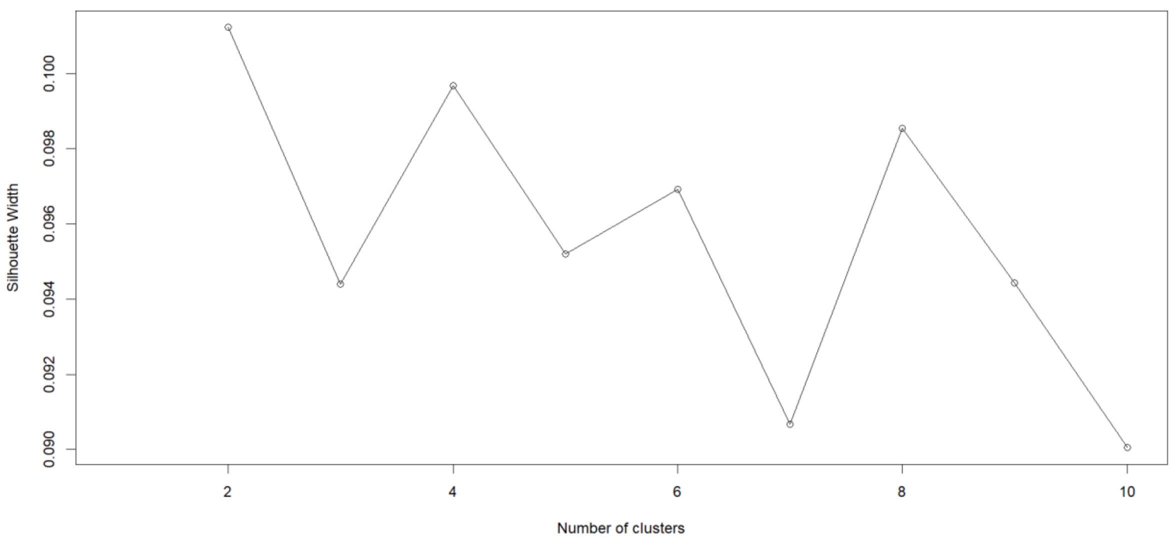

Figure 13. Plot of silhouette widths as output from K - medoids cluster analysis described above. Higher silhouette width values suggest a more accurate number of clusters.

2.4.4.2. Species Richness Index (SRI).

The first index, Species Richness (SRI), was chosen due to its simplicity and inability to be misconceived. The concept first established in the 1940's (Fisher, Corbet and Williams, 1943), and later clarified and popularised in the 1960's (McIntosh, 1967), has multiple different calculations in the present day, but the most simplest form is the absolute number of species in a given area (Whittaker, Willis and Field, 2001). Estimates of the Species Richness Index (SRI) were calculated for each camp using *RStudio*®, based on wildlife activity data only, using the *plyr* package and *richness* command. SRI is calculated as: $\sum_{i=1}^{x} n$, where n = the number of species detected, and is defined as the total number of species found within a defined area (Moore, 2013). Therefore, SRI calculated throughout these analyses is a measure of alpha diversity, as it is calculated per camp within the defined study area. Alpha diversity (Whittaker, 1972) is the mean species diversity at a specific location that can be compared with other specific locations at a local scale. The study area is within a region that is smaller than the entire distribution of the species measured, so given that camp by camp comparison is an aim of this study, alpha diversity is considered the optimum measure. SRI can be interpreted as a higher index value indicating higher biodiversity and therefore a more species rich location. Assigned scores for SRI are displayed in Table 5.

2.4.4.3. Simpson's Index of Diversity (SID).

This index was also generated in *RStudio*® using the *vegan* and *plyr* packages. Again, only wildlife detection data was used to calculate estimates of this index for each camp. There are multiple ways in which Simpson's diversity can be calculated and therefore interpreted (Simpson, 1949). Its function is to measure species diversity within a community and its definition can be simplified to the probability that two individuals randomly and independently chosen (in this case one individual from two different camps) will belong to the same taxonomic group – in this case species (Simpson, 1949).

Shannon's Index and Simpson's Index are two of the traditional diversity indices used throughout ecological literature (Izsák and Papp, 2000). While they both aim to explain diversity, both define the term differently. Simpson (Simpson, 1949), introduced the concept of diversity whereby both richness and evenness are accounted for, and the version of the index used in this study (Simpson's Index of Diversity) measures the probability that two individuals from a sample will belong to the same species. Richness is defined above, while evenness measures the equality of species abundances in a community, maximum evenness occurs when all species are equally abundant (Alatalo, 1981). While Shannon's Index also aims to measure both richness and evenness, a study comparing the two indices found that Shannon's Index is more strongly influenced by richness (almost twice as much weight given to richness than eveneness) and that Simpson's Index is influenced by evenness much more than Shannon's (DeJong, 1975). It is evident that in calculating diversity, both indices place different weighting on either concept (richness or evenness). Ultimately Simpson's Index was chosen for this study as SRI already takes richness into account and the evenness characteristic of Simpson's Index may reveal slight differences which are valuable when comparing locations.

Simpson's Index of Diversity was also chosen as the most appropriate for this data because has the most logical interpretation. The values range from zero (no diversity) to one, with the latter value representing the highest diversity. Simpson's Index of Diversity is calculated as 1- D, where D = $\sum_{i=0}^{x} iPi\ ^2$, where P_i ($P_i = \frac{Xi}{N}$) is the species proportion, x_i is the total number of each species recorded and N is the total number of individuals. Calculation of this index was carried out using the *index = Simpson* command in the *vegan* package. The resulting scores for SID are displayed in Table 5.

2.4.4.4. Subjective Natural Ecosystem Integrity Index (SNEII).

Following the three rounds of data collection and prior to any analyses, a subjective natural ecosystem integrity index (SNEII) was devised, as an alternative means of assessing the ecological intactness of a camp and the level of degradation, if any, exhibited over the course of the study. This index was created by assigning each camp a score from 0 to 100 %. A score of zero represents a fully domesticated camp, where human settlement has long been established and the livelihood-related resource utilisation activities that are associated with permanent settlement, such as land clearing, agriculture, and other resource extraction practices such as charcoal burning are ubiquitous. At the other end of the scale, a score of 100 represents a fully pristine, natural ecosystem, with no evidence of human exploitation of any kind. Individual scores were carefully assigned based on a consensus reached through discussions of the investigators on the field team, based on their recollections. Field notes that were recorded during the study and any photographs that were taken were carefully considered during these discussions. Due consideration was also given to the time of year a camp was visited and the frequency with which it was surveyed. Seasonality can impact upon the level of groundwater available and therefore either hinder (e.g., fully flooded – limiting accessibility or tall vegetation limiting visibility) or enhance (e.g., soft, damp soil ideal for recording tracks and signs) the detectability of human activities. *Subjective Natural Ecosystem Integrity Index* (SNEII) was formulated in December 2022, immediately after data collection was completed. The scores were then drafted and finalised in *Excel*®.

The primary and most important criteria for assigning an ecosystem integrity score was based on the subjective impressions of the intensity of land degradation caused by the conversion of land for agriculture, deforestation for the purposes of charcoal production, timber harvesting or human settlement and for livestock herding. The intensity of degradation of the land surrounding a 2km radius of the camp was determined by estimating the proportion of the natural ecosystem remaining more or less intact based on informal personal observations that were made while present in the camp and during camp radial surveys. This subjectively estimated proportion of intact land was then used as a reference point for initiating the discussions that concluded with the assignment of the score. For example, a camp with an estimated 10% of land that was considered ecologically intact was initially given an approximate score of 10. Camps that evidently belonged on the extreme ends of the scale were assigned first, to provide clear reference points, before those that were less clear and required a more in depth-discussion. The majority of camps that required extra discussion were areas where intermittent patches of deforestation, small-scale agriculture and human settlement existed in amongst expanses of intact woodland or forest. These were all located inside ILUMA WMA, in areas that were either regenerating from previous encroachment, or beginning to experience an influx of human activities.

The investigators recollections regarding the abundance of wildlife and humans as indicators of ecosystem integrity featured less in conversation when assigning scores but were nevertheless useful as secondary factors to be considered following the discussion of the intensity of land degradation. Recollections of the investigators personal observations clearly indicated that species diversity generally increased with intact natural land cover and that some species were found more often than others in areas of degraded land. These criteria were useful when deciphering the scores of multiple camps within ILUMA that seemed to have similar levels of intact woodland or forest and degradation. It also proved useful for areas of regenerating woodland that had been previously degraded by humans. Regenerated woodland with signs of high species diversity tended to result in a higher ecosystem integrity score being assigned, whereas woodlands in the early stages of regeneration that appeared to have low wildlife diversity were assigned lower ecosystem integrity score. However, considerations of perceived wildlife population characteristics as an indicator of ecosystem integrity proved somewhat complex and uncertain, as wildlife communities' composition and diversity naturally change with historical and actual land cover. The ability to distinguish historical and current land cover types was also an important factor when assigning the values for this index, as it was vital to not mistake natural grasslands, scrublands, and valleys for areas that had been deforested.

Based on subjective impressions, it seemed the presence of humans was negatively associated with natural ecosystem integrity. However, it was not a consistently reliable criterion as some human activities had little to no impact on their surrounding environment. For example, small, legal fishing camps along the banks of the Kilombero river in the north of ILUMA (camp numbers 14, 15 and 26) are long-established settlements but were assigned high ecosystem integrity scores (Table 5 and section *3.4.5.*).

Although meat and fish poaching were not noticeably associated with direct effects on ecosystem integrity, any evidence of these illegal activities also led to the investigators assigning slightly lower scores depending on the intensity observed.

After discussion and the initial ecosystem integrity index was drafted, the scores were reviewed again to ensure that the order and distribution of the natural ecosystem integrity index scores were assigned as well as possible regarding the above criteria. No two camps were assigned exactly the same score and the difference in value between scores to be reasonably representative of the magnitude of their *de facto* differences. Assigned scores for the SNEII are displayed in Table 5 and used in the subsequent analyses in section *2.4.5.*

2.4.4.5. Objective Natural Animal Community Integrity Index (ONACII).

The data reduction analysis used to generate an objective natural ecosystem integrity index was carried out in *RStudio*® using the *factoextra* package. ONACII is a synthetic composite indicator based on principal component analysis (PCA) of values for all the various types of detections of all the wildlife species for each camp in the processed datasets prepared as described in section *2.3.2.7.* Wild herbivore, wild carnivore, wild rodent and wild primate, and prosimian detection data were used to generate this index and designate a score for each camp. Scores obtained from the PCA range from -8.8, where the lowest number of detections of different types of direct sighting, tracks, spoor, and other signs of wildlife activity was recorded, to 30.1 where the highest numbers were observed. To make these values easier to interpret, they were scaled using their Z-score means. Z-score means were calculated in *Excel*® using the following formula: $\frac{x_{i-}\bar{x}}{\sigma}$, where x_i is the PCA score for camp i, $\bar{x}$ is the mean value of PCA scores across all camps and σ is the standard deviation of the PCA scores across all camps. These normalised scores centred around zero and ranged from -0.85 to 2.92 (lowest to highest). The results of this calculation are reported in Table 5.

2.4.4.6. Objective Natural Ecosystem Integrity Index (ONEII).

Analysis was carried out in *RStudio®* using the *factoextra* package. Objective Natural Ecosystem Integrity Index is a PCA based index of all of the recorded detections of wildlife, livestock, and humans, and also the summary indicators of land cover at each camp. This index combines all the recorded indicators of wildness with those of encroachment to provide a composite score for comparing the ecological status of different camps. Values range from 87.7 which was the lowest score and indicates that the ecosystem has experienced much human interference and signs of wildlife activity was the lowest recorded, to -13.6 which exhibited the most evidence of wildlife activity and the lowest levels of human activity. Again, to make these values easier to interpret, they were scaled as their Z – score means, using the same methodology outlined in section *2.4.4.5.* these normalised means ranged from 3.8 to -0.59 for the most degraded to the most pristine, with the lowest ranked camp being represented by the highest value. The results of this calculation are reported in Table 5 and used in subsequent analyses in section *2.4.5.*

2.4.5. Comparison of novel Subjective Natural Ecosystem Integrity Index (SNEII) and PCA-based Objective Natural Ecosystem Integrity Index (ONEII).

Analysis was carried out in *RStudio®* using the *ggpbr* package while *ggplot2* and *scales* were used for graphing.

In order to test the utility of the novel Subjective Natural Ecosystem Integrity Index (SNEII) developed for this study and also reported in Walsh *et al.* (forthcoming), correlation between it and Objective Natural Ecosystem Integrity Index (ONEII) described in section *2.4.4.6* were assessed in a non-parametric manner using the Spearman's ranked correlation test. This analysis was intended to evaluate the robustness of SNEII, as ONEII is PCA based and takes all empirically recorded variables into account when generating an objective score. Spearman's ranked correlation test was chosen as the correlation test method, as it assesses how well the relationship between two sets of ranks can be described using a monotonic function. Firstly, the previously scaled (section *2.4.4.6*) ONEII scores were ranked using the "rank" command in RStudio. Then the correlation test was carried out specifying the method as "spearman" to produce a ρ value and P value. In order to fully visualise this relationship, this result was graphed using the *ggplot2* and *scales* packages (see Figure 43).

2.5. Impact of human activities on ecological indices.

In an effort to determine which human activities had the most severe impact on the ecological indices, GLM analysis was undertaken on each index individually as alternative dependent variables as potential indicators of natural ecosystem integrity, details of which are described in sections *2.5.1.1* to *2.5.1.4.* One exception is that GLM analysis was not carried out on ONEII as variables relating to human activity were used in creating this index, so testing for their association with this derived index would be confounded by circular logic. Each human activity was firstly scaled using Z-score means, using the same calculation method described in section *2.4.4.4*. GLM analysis was then carried out in *RStudio*® using the *lme4* package and the processed form of the data described in section *2.3.2.7.*

2.5.1. Species Richness Index (SRI).

A histogram of the distribution of scores for SRI was first plotted using the *hist* function in *RStudio*®. This verified that the data appeared to be normally distributed. Next, a series of GLMs with a single explanatory variable were fitted defining SRI as the dependent variable and one given human activity as the sole independent variable. Multiple distributions and link functions were specified until the best fit model with the lowest AIC score was identified. The selected best-fit distribution for SRI was Gaussian family with an inverse link. An intercept of zero was specified to allow the parameter estimate results to be interpreted in relation to totally pristine conditions. Multiple GLM analyses with a single explanatory variable were run using each human activity as the independent variable. GLM analyses with multiple explanatory variables were then carried out using forward stepwise selection procedure to build the most informative and parsimonious explanatory model possible, beginning with the human activity variable with the lowest P value in single explanatory variable analysis, which was livestock herding in this case. Human activities were added and removed from the model based on objective criteria specified *a priory*, until the best fit model based on AIC score was produced: each retained variable was required to at least approach significance in the model it was included in and significantly improve the goodness of fit relative to the otherwise equivalent model from which it was excluded. The results of both single explanatory variable and multiple explanatory variable analyses on species richness index are presented in Table 6 of results section.

2.5.2. Simpson's Index of Diversity (SID).

A histogram of the distribution of scores for SID was first plotted using the *hist* function in *RStudio*®, which revealed a skewed distribution. Next, a series of univariate GLMs were fitted defining SID as the dependent variable and a given human activity as the independent variable. As per section *2.5.1*, multiple distribution types and link functions were specified until the best fit model with the lowest AIC score was produced. The selected best-fit distribution was Gamma family with a log link function. Again, an intercept of zero was specified to allow the results to be interpreted relative to totally pristine conditions. Multiple GLM analyses with single explanatory variables were carried out using each human activity as an alternative single independent variable. GLM analysis with multiple explanatory variables then proceeded, beginning with the human activity that had the lowest P value from univariate analysis, which again, as was the case for SRI, was livestock herding. Again, human activities were added to the model using the same objective forward stepwise selection procedure, until the best fit model based on AIC score was identified. The results of both single explanatory variable and multiple explanatory variable analyses on SID are presented in Table 7 of results section.

2.5.3. Subjective Natural Ecosystem Integrity Score (SNEII).

As with the previous two indices, a histogram of the distribution of scores for SNEII was plotted. In this case the distribution appeared to be normal. After a series of GLMs with single explanatory variables were fitted that defined SNEII as the dependent variables and each of the human activities as alternative sole independent variables with multiple alternative distributions and link functions for the dependent variable examined. The Gaussian family without any link function was chosen as the best fit distribution based on the optimum AIC score. Again, to interpret the results relative to totally pristine conditions, an intercept of zero was again specified. Each human activity's individual impact was tested as a determinant of SNEII in a series of single explanatory variables GLMs. Then analyses with multiple exploratory variables were carried out using the same objective forward stepwise selection procedure described in section *2.5.1.* The model building process started with tillage farming for this index, as it had the lowest P value from univariate analysis and further human activities were added to the model until the best fit model was produced. The results of both single explanatory variable and multiple explanatory variable analyses on SNEII are presented in Table 8 of results section.

2.5.4. Objective Natural Animal Community Integrity Index (ONACII).

Just as in sections *2.5.1, 2.5.2* and *2.5.3*, a histogram was plotted to examine the distribution of ONACII scores, which exhibited a normal Gaussian distribution. Multiple GLMs with ONACII as the dependent variable and individual human activities as the alternative sole independent variable were fitted using different distributions and link functions until a best fit option was identified. Gaussian family without any link function had the lowest AIC score and was the model chosen for subsequent analyses. Each human activity's association with ONACII was tested in a series of single explanatory variable GLMs with no intercept specified. Analysis with multiple explanatory variables was then performed as in the previous sections, again beginning with livestock herding as it had the lowest P value in single explanatory variable analysis. The best fit model was produced by adding and removing human activities in order of significance through an objective forward stepwise selection procedure until the model with the lowest AIC was identified. The results of both single explanatory variable and multiple explanatory variable analyses on ONACII are presented in Table 9 of results section.

2.6. Geographical data distribution and geographic distribution representation.

The figures displayed in results section that are not explicitly explained throughout the methodology are dot plots, created using the *ggplot2* package in *RStudio*® and using the data processed as described in section *2.3.2.6*. All other figures are maps which were drafted using QGIS version 3.28.2., with built in layers from OpenStreetMap® and Google Maps® in the XYZ Tiles pane, and shapefiles of the study area created using collected GPS coordinates.

3. Results.

3.1. Transect surveys and camp radial surveys detections.

3.1.1. Total frequencies of wild herbivores, wild carnivores, and wild primates.

Direct sightings, tracks, spoor and other signs (such as bark scratching by elephants or broken shells gathered by water mongoose) of each species were examined to give both overall totals and per radial survey or per transect survey segment per species. Direct sightings was the category with the lowest number of detections consistently throughout all wild herbivore and wild carnivore species. Wild herbivores were the group detected most frequently, followed by wild carnivores and wild primates respectively. Detection methods differed from species to species, direct sightings was almost always the detection category observed the least. As detailed in Appendix 1 and illustrated in Figures 14 and 15, a diversity of wild herbivores was detected across the study area at different frequencies. Elephant were by far the most detected species, with a total of 1256 different detections, this is more than 26% greater than the next most frequently detected wild species, namely hartebeest, and 33% greater than African buffalo. The large variation in detections in species is evident when the most frequently detected (elephant) is compared to the least frequently detected (wildebeest), in which there is a 1256-fold difference. Only two wild herbivore species were detected less than ten times: puku and wildebeest.

This difference in detection frequency between hartebeest and wildebeest displays a clear contrast in detectable activity in *Alcephaline* subfamily the during the course of this study in this particular area. Puku was the least frequently detected of *Reduncini* subfamily in the survey area, while reedbuck and waterbuck were much more common. Waterbuck displays a clear increase in detected activity as one moves across the study area starting in western locations from the fully domesticated areas outside ILUMA, through the gradient of degraded to pristine areas (as defined in section *3.4.1.*) inside, and then into NNP, where a sharp increase in detections is recorded. Steady gradient of detected activity is not displayed by reedbuck which appear most abundant inside ILUMA's boundaries. Very few recordings of either species were made in the degraded areas outside ILUMA.

Tracks were the most common way in which *Reduncini* were detected, followed closely by spoor. Of the spiral horned antelopes recorded in this study Bushbuck, follow the trend noted in *Reduncini* with tracks being the detection method most often recorded. For Common Eland and Greater Kudu however, the most typical method of detection was spoor. Greater Kudu were recorded over 4.3-fold less than Bushbuck, and 5.6-fold less than Eland, they are not only the least frequently detected of the spiral horned antelopes, but also one of the least common herbivores throughout the entire study.

Noticeable differences are also detected within family *Suidae*. Warthog was detected > 90% less frequently than Bushpig. Almost 14% of Warthog detections were direct sightings. Direct sightings were never detected for Bushpig. Spoor was consistently the lowest detection category for *Suidae*. This family is also the group with the highest proportion of detections of other signs amongst all wild herbivores - almost one third of *Suidae* detections were in this category.

The only other wild herbivore with a similar number of detections of other signs was elephant. Hippopotamus had similar levels of detection for both tracks and spoor which resonates well with the elephant, however a clear difference is detected between these species when other signs are compared; other signs of elephants that were frequently recorded include bark being stripped from trees, branches broken and chewed, and mud covering the trunks of trees. Tracks and spoor were also the most common ways in which African buffalo and plains zebra were detected, with both exhibiting low frequencies of direct sighting and other signs.

One of the most striking differences in detections occurred within the *Cephalophini* subfamily. Common duiker was detected more than 9 times more frequently than Red Duiker. No record of Red Duiker spoor or other signs were detected over the entire course of the study and this species was detected only during the camp radial surveys. Similarly, common duiker also was detected far more commonly during camp radial surveys than transect surveys. Sharpe's grysbok and dikdik were both detected far less frequently elephant, hartebeest and African Buffalo, and for both, other signs did not feature.

Spoor was the most commonly recorded sign of impala activity. This species was never recorded in the degraded areas outside ILUMA conservation area, and only rarely detected inside it (see Figures 14P and 15P). However, a sharp increase in detected activity occurs inside NNP where the habitat changes from miombo woodland to acacia savanna. It should also be noted that the camps inside NNP were each visited only once, therefore the comparable number of Impala to other herbivore species found readily in ILUMA may actually be much higher than reported here.

Unsurprisingly, wild carnivores were far less frequently detected than herbivores (Figures 16 and 17) in every category (see Appendix 1). Lions were detected only occasionally and only by their tracks, with similar detection rates between radial and transect surveys. A leopard was sighted once in direct sightings but detected far more frequently based on their tracks and spoor. Tracks were the most frequently recorded detection category for both African wild cat and spotted hyena. However, while detection frequency of spoor was very similar to tracks for spotted hyena in transect surveys, presumably because footprints dominated hyena detections in radial surveys, African wild cat tracks accounted for 82% of all detections for the species. Almost two thirds of all hyena detections occurred in transect segment surveys (Figures 16L and 17I).

Canidae was the family with the least detections, with only three recordings of Side-Striped Jackal tracks and African Wild Dog was never detected. *Mustelidae* were detected only six times, all of which related to African clawless otter. Four species of *Herpestidae* were detected in the study. With less than ten total observations combined slender mongoose, banded mongoose and white-tailed mongoose appeared to be quite scarce. This contrasts sharply with water mongoose, which was by far the most commonly detected carnivore with almost three hundred individual records. The majority of water mongoose detections occurred on camp radial surveys, with tracks being the most frequent way in which they were detected. Water mongoose spoor was detected marginally more often than other signs, of which over 92% were detected on camp radial survey.

Direct sightings and tracks contributed to the majority of primate detections, wherein baboons were the most frequently detected primate, accounting for almost 70% of all primate detections.

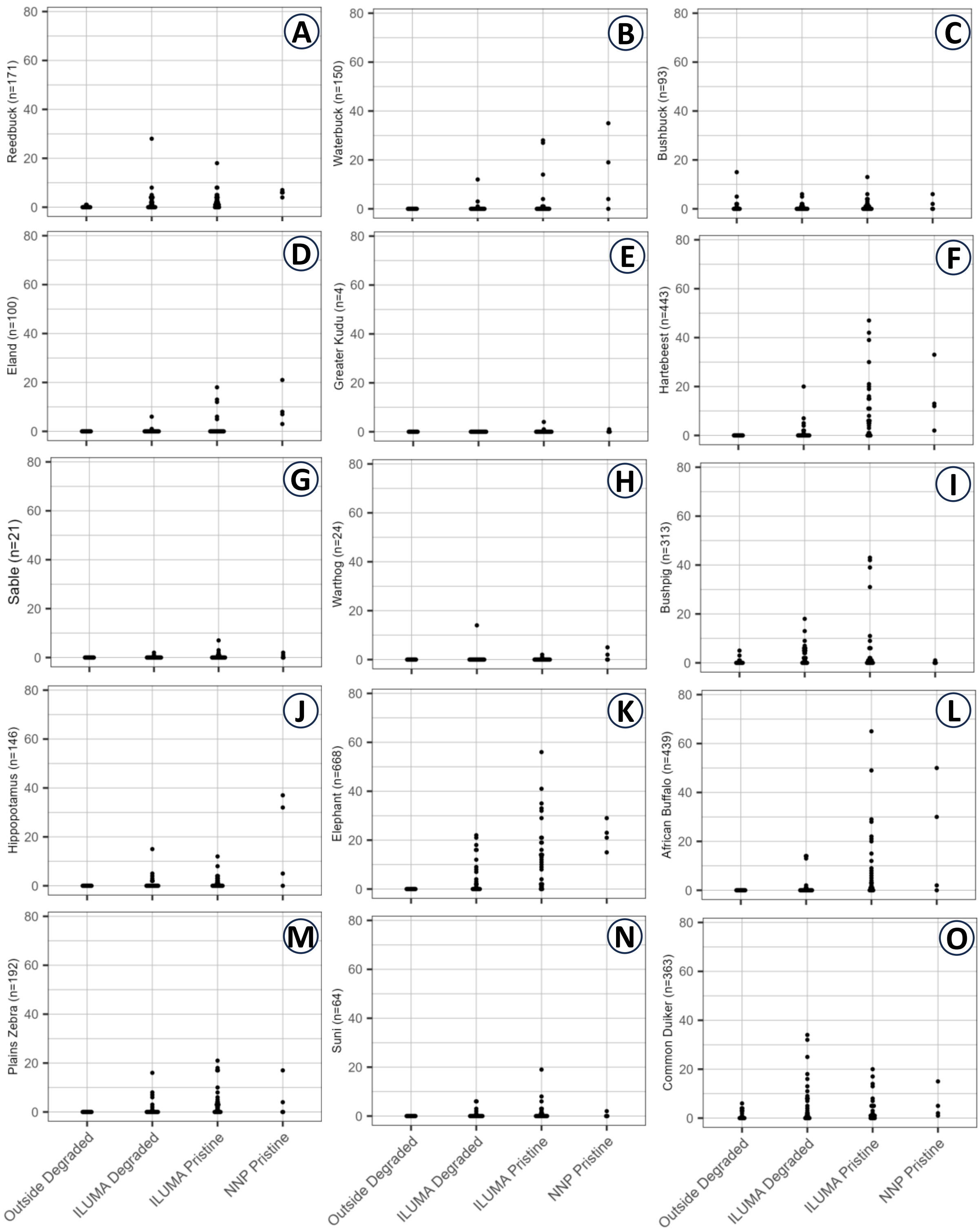

Figure 14. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild herbivores detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

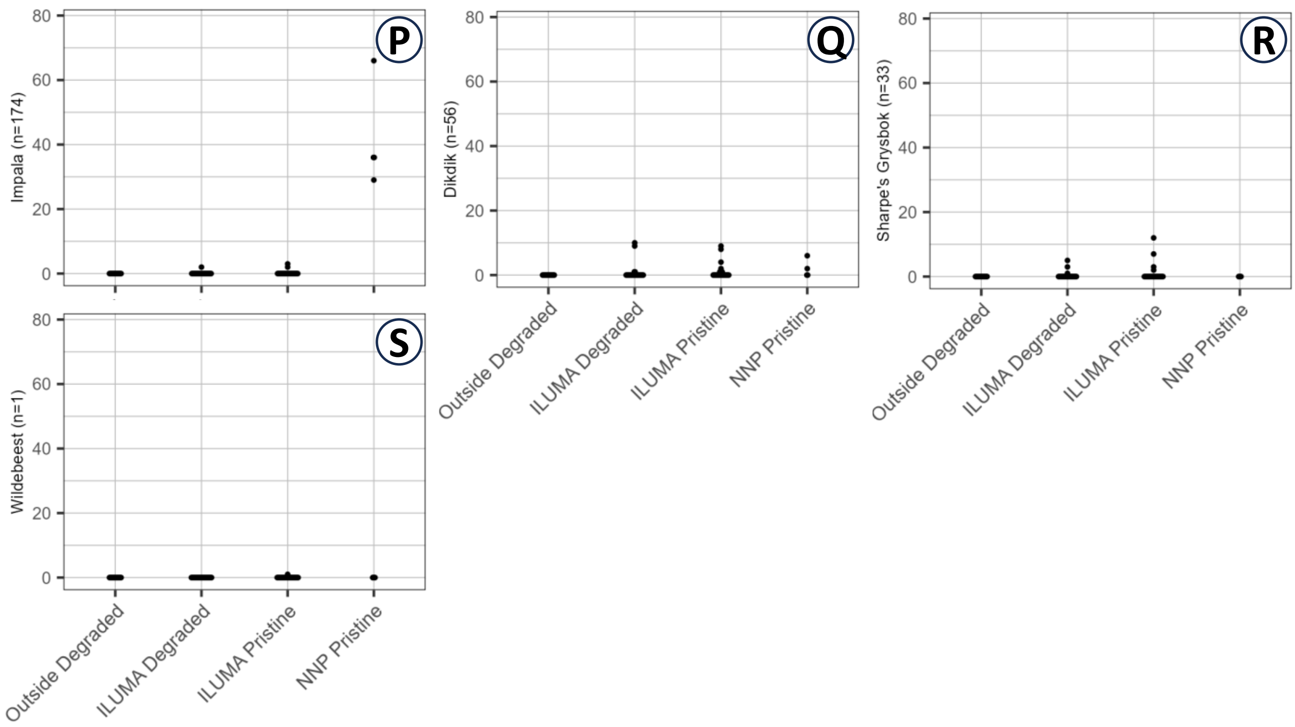

Figure 14. Continued. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild herbivores detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

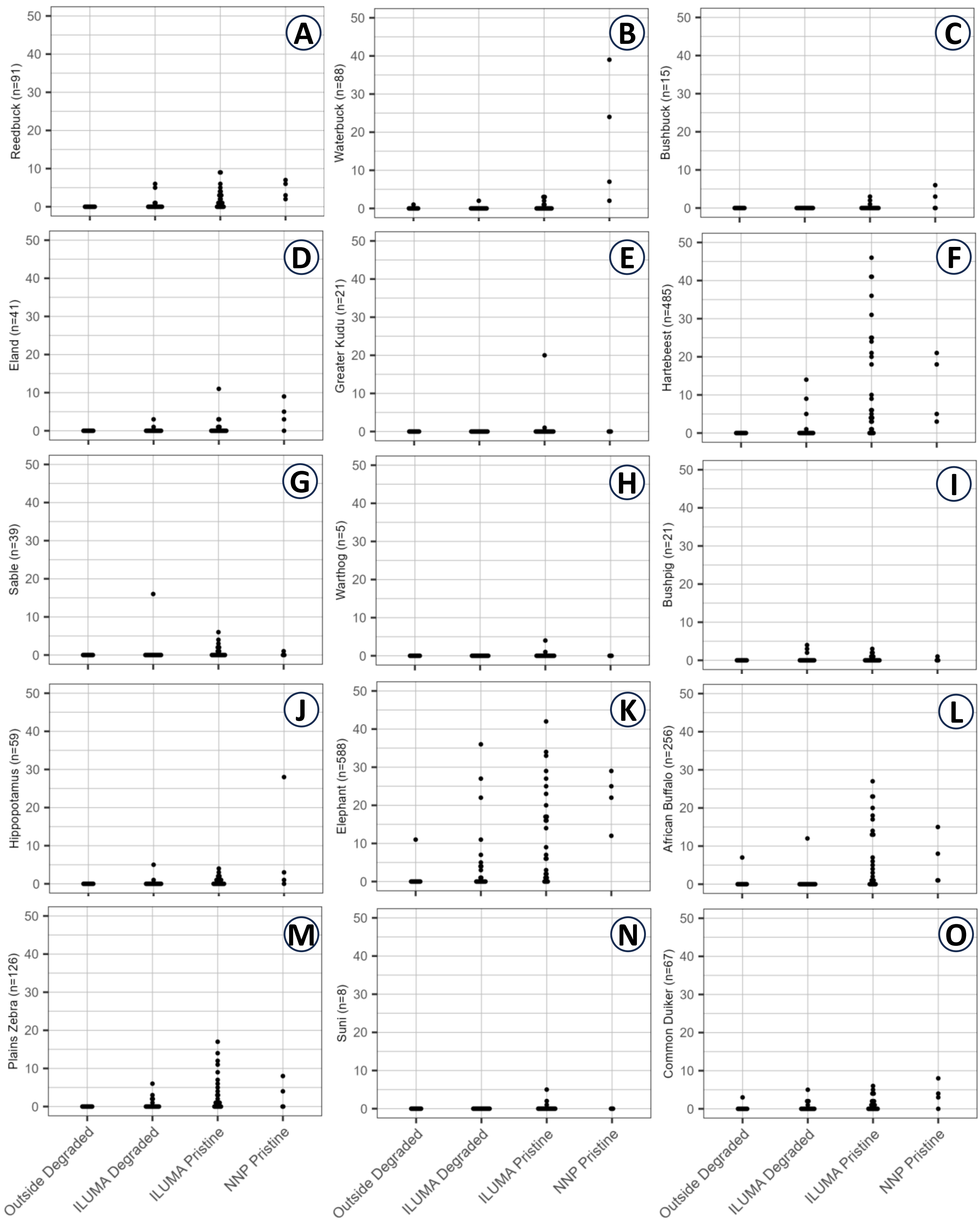

Figure 15. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild herbivores detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

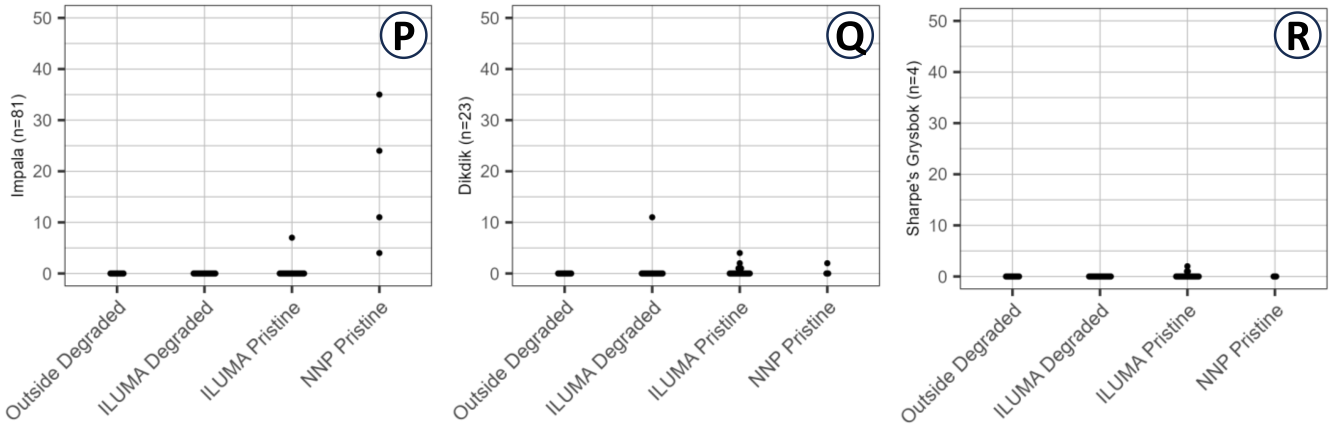

Figure 15. **Continued.** Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild herbivores detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

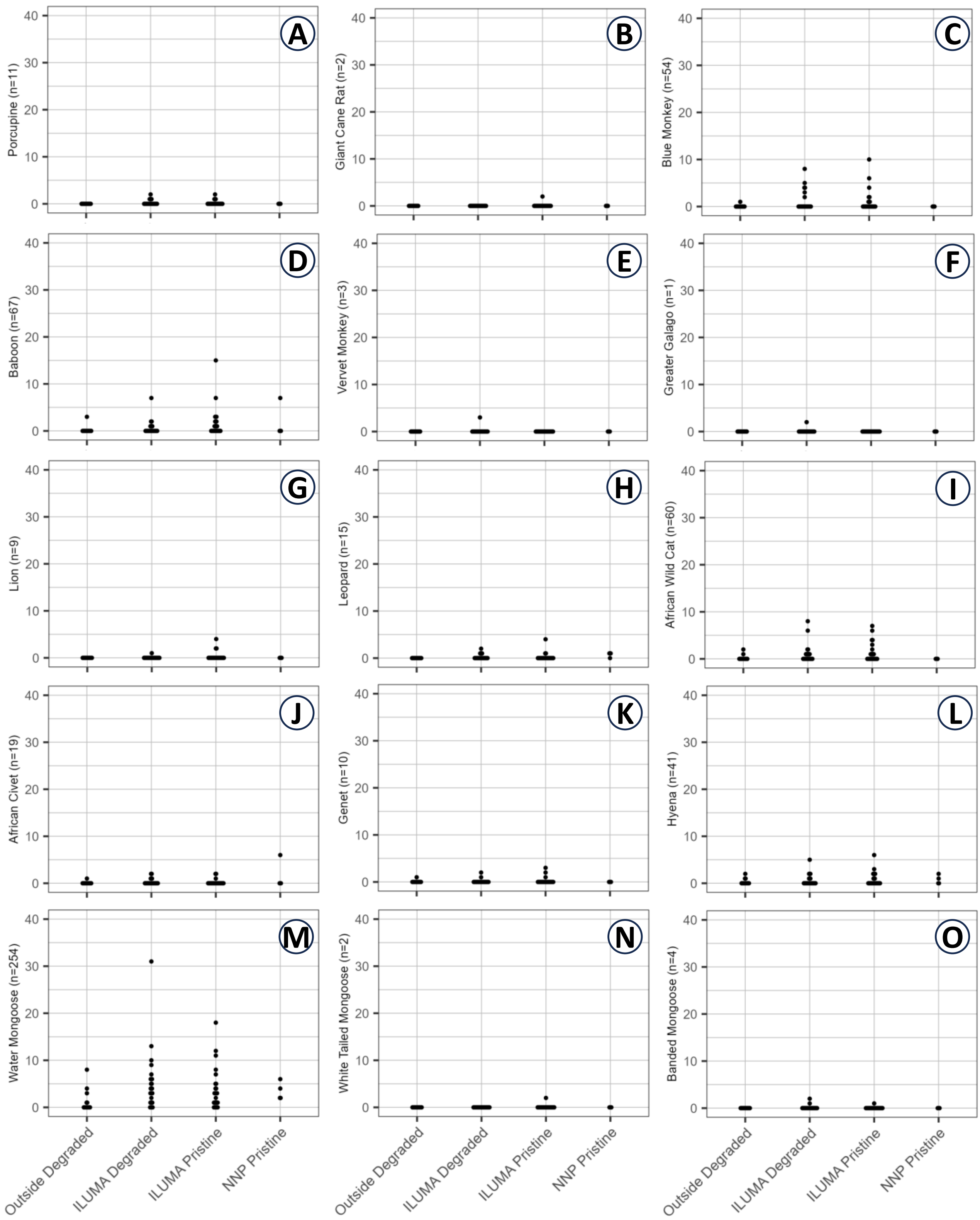

Figure 16. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild rodents, wild primates and prosimians and wild carnivores detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

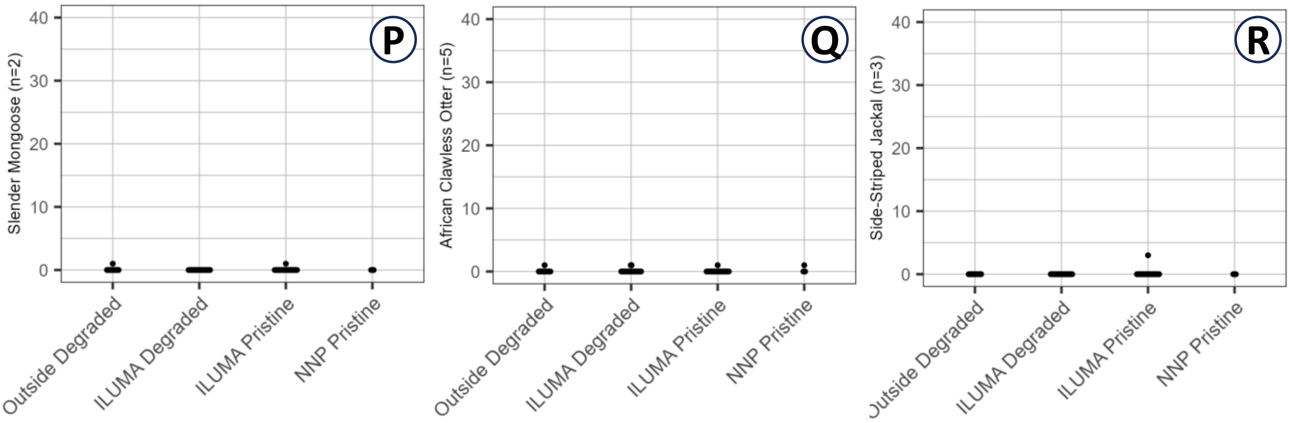

Figure 16. Continued. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild rodents, wild primates and prosimians and wild carnivores detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

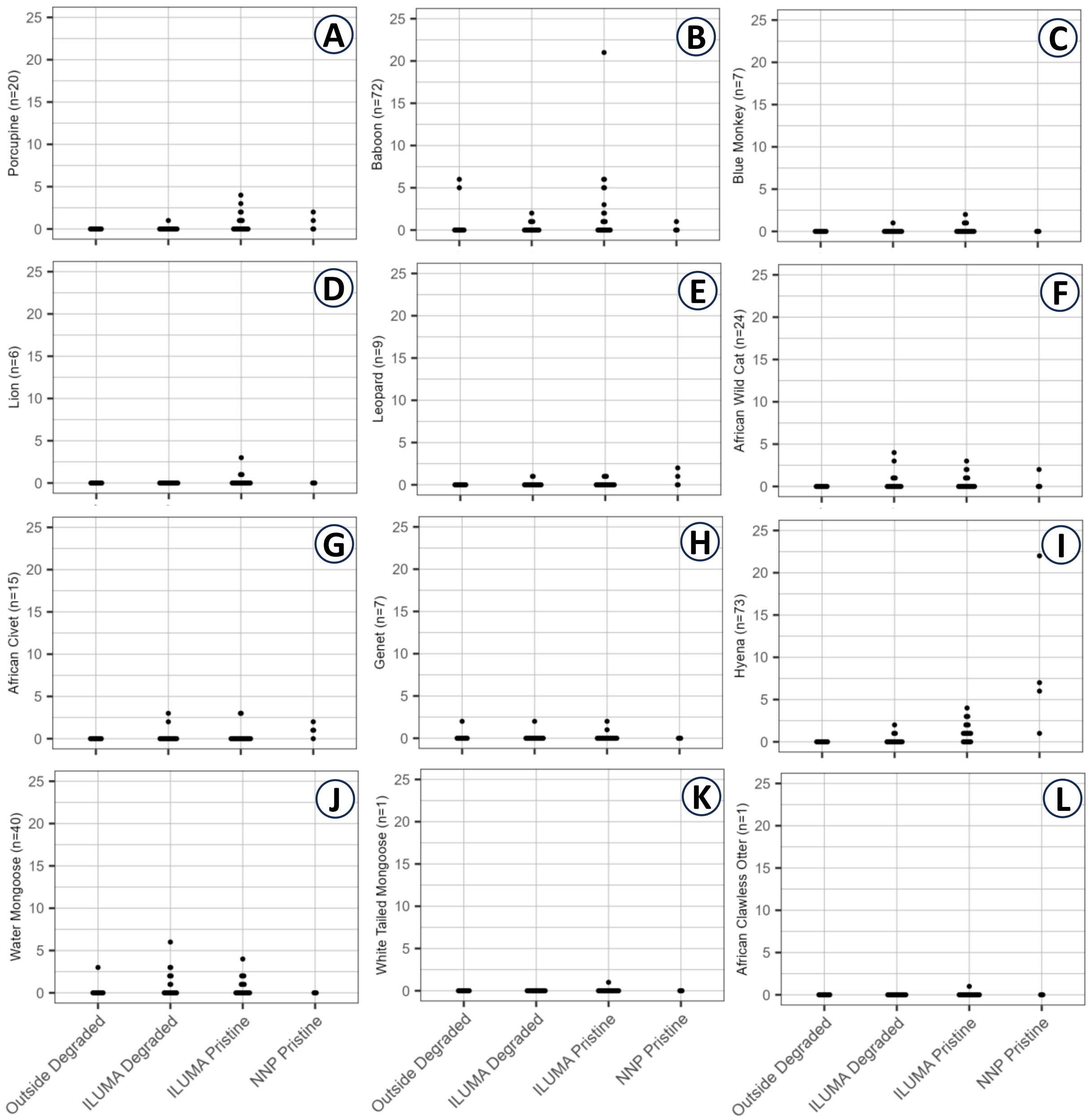

Figure 17. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all wild rodents, wild primates and prosimians and wild carnivores detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific species was observed in that particular combination of detection type and location.

3.2. Occurrences of humans, human activities, and livestock.

3.2.1. Humans.

Eleven different categories of human presence and activity were detected over the course of the study (Appendix 1 and Figures 18 and 19). Authorised presence of community members both outside and inside ILUMA WMA accounted for the vast majority of all detections. Almost 1200 different detections of lawful community presence were detected outside ILUMA's boundaries throughout the three survey rounds. The majority of these detections were made in the villages to the west of ILUMA. These areas were surveyed to enable comparison between ecologically degraded, fully domesticated habitats outside a WMA and the most pristine ecologically intact areas within and to enable comparative quantitative assessment of intermediate areas lying along the gradient between these two extremes.

Some authorised settlements are permitted inside the WMA as agreed as part of the participatory land use plan that underpins it (District Authorities Local Government Act, chapter 287, 2016). These are all long-established fishing camps along the banks of the Kilombero river, the occupants of these designated locations composed the next largest group of humans detected throughout the study. Of the detections of humans encountered either outside the conservation area, or inside with authorisation, only a quarter were in the latter category. These fishing camp settlements are smaller in number and size, than villages outside the conservation area. Some of these detections also account for permitted natural resource extraction activities within the WMA, largely fish harvesting and fish transport by residents of these permitted settlements. No evidence of unauthorised fish transport was ever detected and just 22 detections of persons harvesting fish without permission occurred. Note, however that the detections detailed in Appendix 1 relate only to observations of humans actually carrying out the activity, rather than any other indirect evidence of the activity occurring or having occurred, for the latter, relating to the frequency of unauthorised human activities detected by any means, see Appendix 2. Unsurprisingly, all of these detections were made during camp radial surveys, which are waterbody centred. The frequency of detection of humans actually carrying out other unauthorised extraction activities as timber harvesters, timber transporters, charcoal burners and charcoal transporters was also very low, totalling only 83 occurrences overall. By comparison, the frequency with which these activities were detected, without direct observations, tracks or other signs were far more common (Appendix 2). Finally, only five official personnel from ILUMA or NNP were ever encountered over the course of the study. Unauthorised human presence within ILUMA accounted for a large number of human detections. Over 600 individual detections of unauthorised humans were made throughout the study.

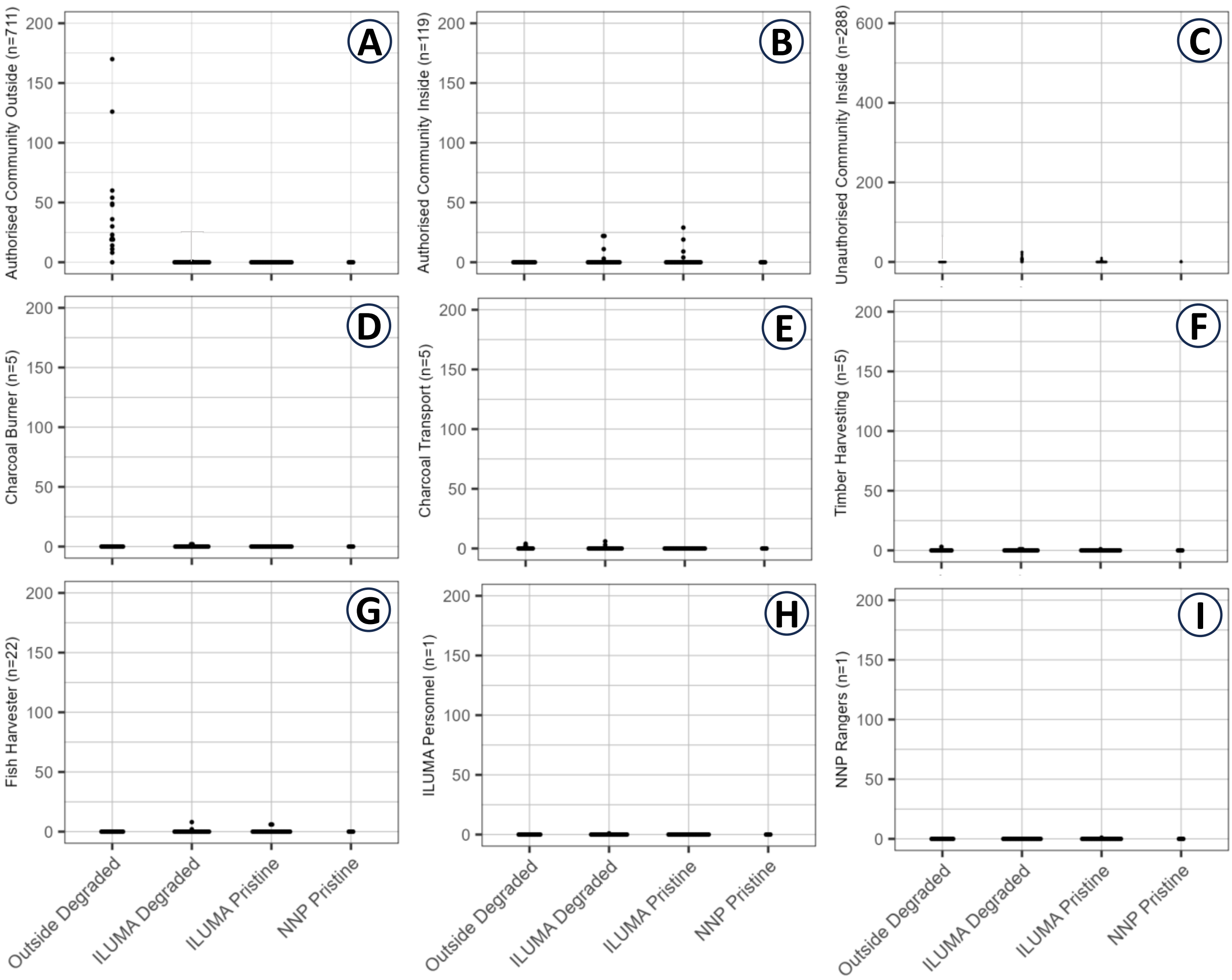

Figure 18. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all humans detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific category of human was observed in that particular combination of detection type and location.

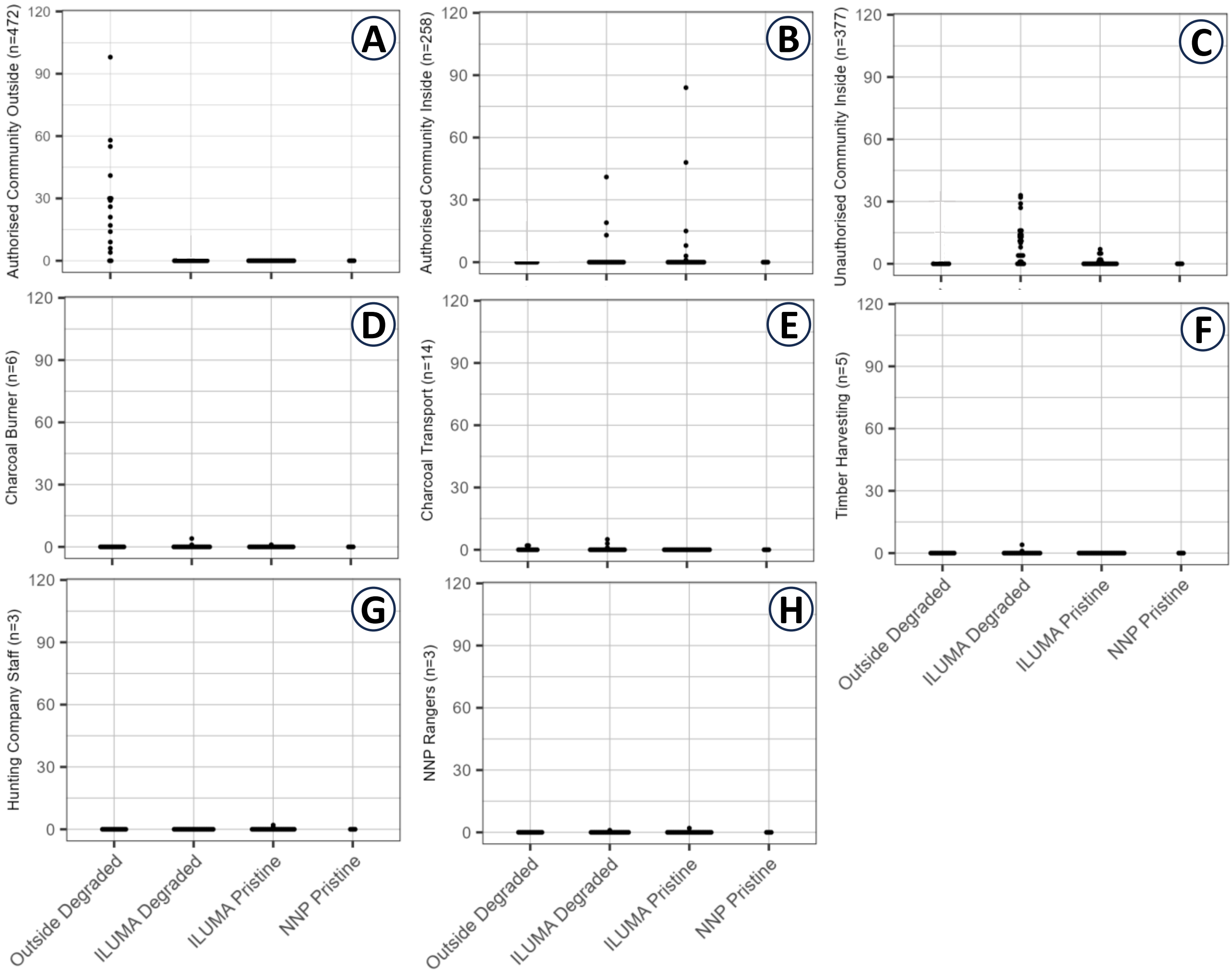

Figure 19. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of all humans detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific category of human was observed in that particular combination of detection type and location.

3.2.2. Human Activities.

As illustrated in Figures 30 and 31, there is a clear gradient in level of farming moving from the degraded environment outside ILUMA and decreasing through its area and over to the boundary of NNP, although no type of agriculture was ever recorded inside the national park (see Figures 20B, 20C, 21B, and 21C). Tillage farming covering greater than 75% of the survey area was never detected in either survey type in the *pristine* camps (see section *3.4.1.*) of ILUMA. Tillage farming was most frequently recorded at 25 and 50% of study area cover and mostly in the degraded ILUMA camps or the degraded area outside. Rice farming was most frequently detected in the degraded camps outside the WMA and in the *degraded* camps (see *3.4.1.*) inside, see Figure 30. Rice farming was recorded more frequently and at larger area of land cover than other tillage crops.

The most common category of human settlement recorded was ten structures or less. These represent small gatherings of dwellings scattered throughout the survey area but never inside NNP, no structures of human settlement were recorded there (see Figures 20A, 21A and 29). A clear decrease in the size of settlements recorded is observed as fewer large settlements were recorded. The large settlements (containing more than 50 structures) were found either outside of ILUMA 's boundary in the villages to the west or in one of the three authorised settlements inside the WMA. Wells for water extraction were far more frequently observed on camp radial surveys, these surveys were however centred specifically around water sources, so this accounts for the large difference in detection. Many were also found in locations with large human settlements (see Figures 20H, 21H and 26).

Evidence of unauthorised hunting was only ever recorded once (as evidenced by discarded equipment) but trapping was detected more frequently, especially during camp radial surveys (Figures 20I, 21I and 27).

In contrast to the detections of humans carrying out unlawful activities within the study area, the frequency of evidence of the activities themselves was much higher. For example, almost 300 separate instances of charcoal burning were detected with more than two thirds of these being detected in camp radial surveys (see Figures 20E, 21E and 23). Timber harvesting and fishing also followed the trend of being detected more often during a radial survey around the camp (Figures 20F, 20G, 21F, 21G, 24 and 25). The number of instances of charcoal burning being detected however, is more than double that of timber harvesting and fishing combined.

Finally, the most frequently observed human activity recorded throughout the study was cattle herding, 951 separate detections of cattle herds were recorded (Figures 20D, 21D and 22). No cattle herding was ever detected in NNP, and this activity was most frequently detected in the *degraded* (see section *3.4.1.*) areas of ILUMA WMA.

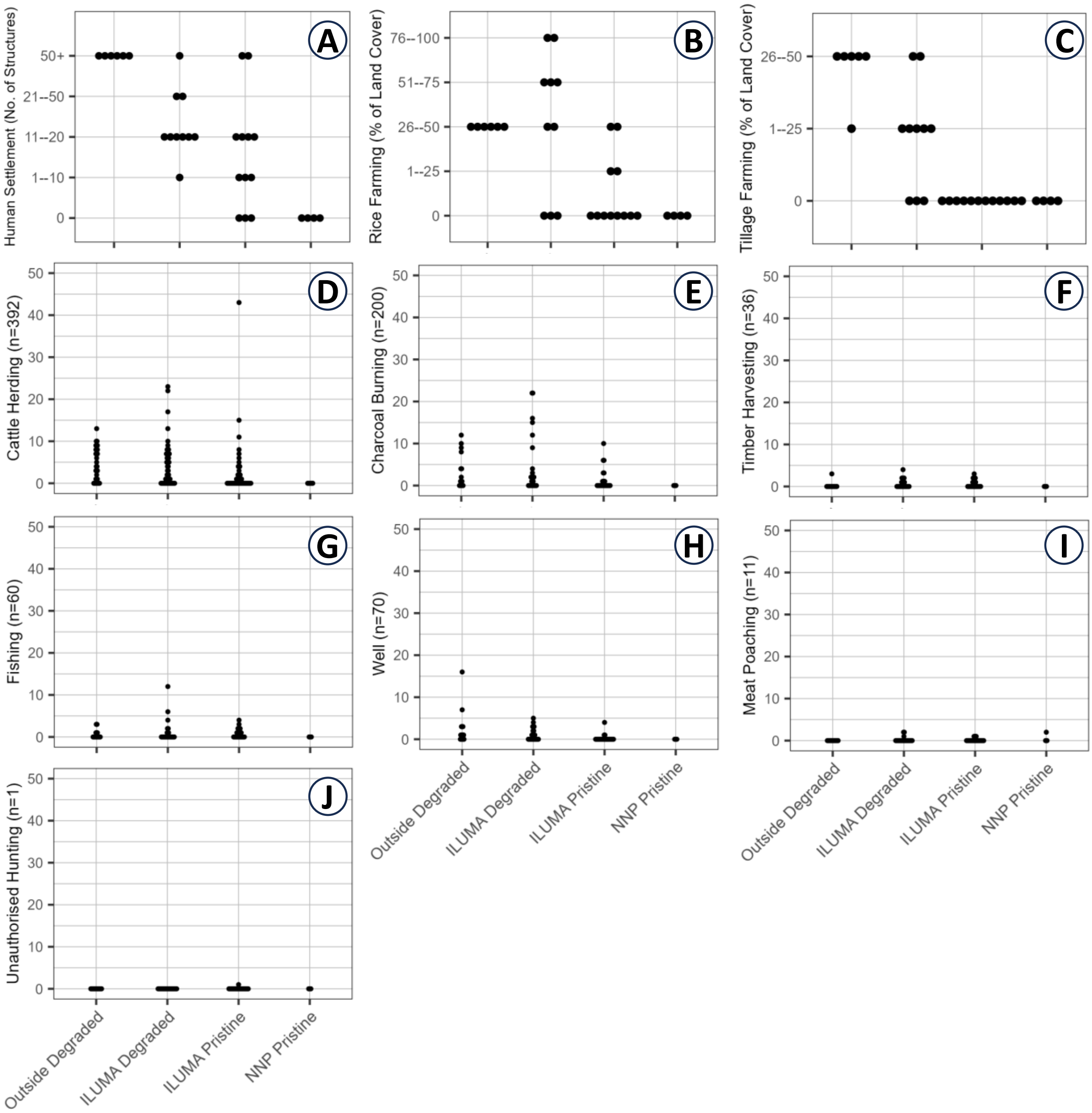

Figure 20. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of human activities detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific activity was observed in that particular combination of detection type and location.

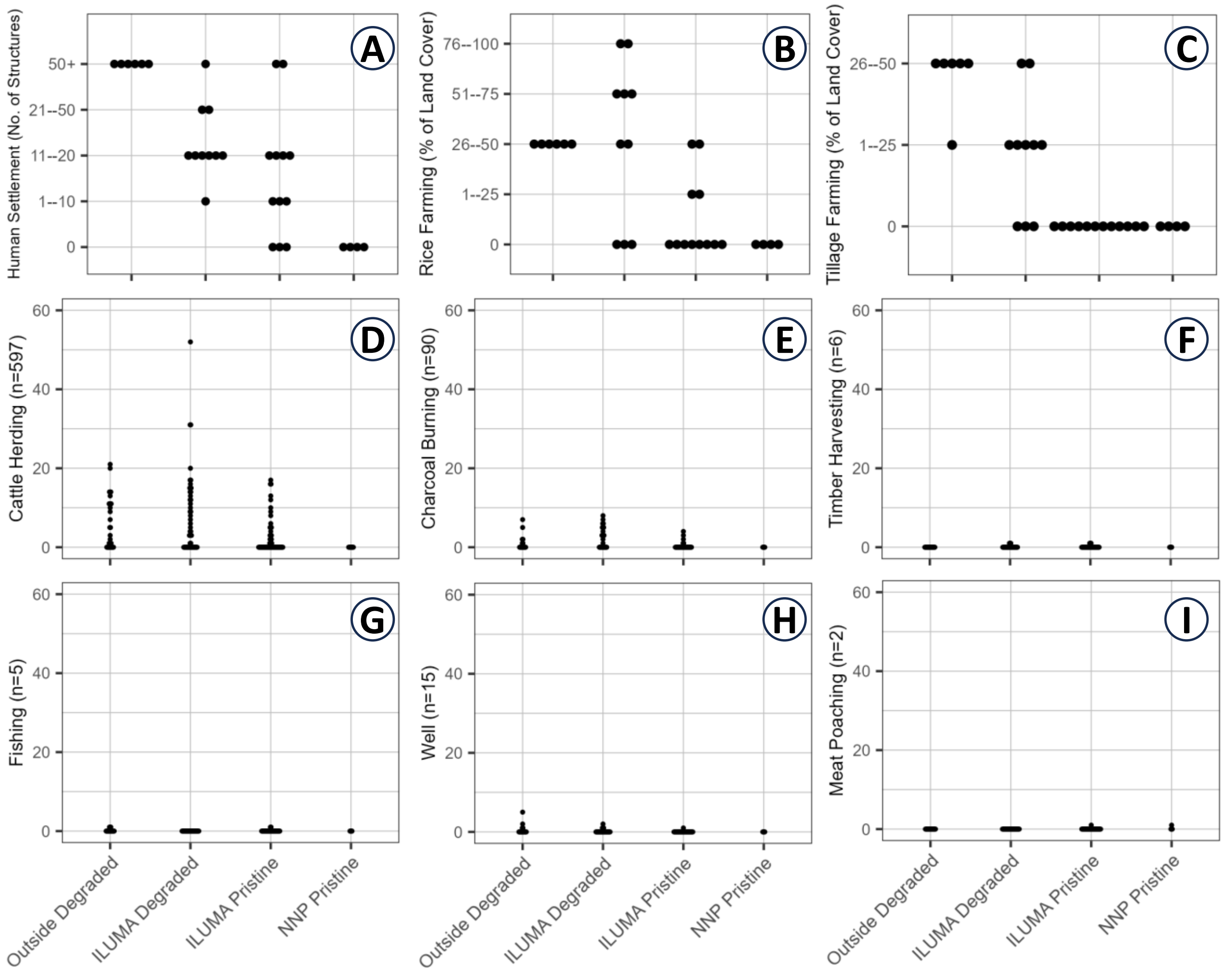

Figure 21. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of human activities detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific activity was observed in that particular combination of detection type and location.

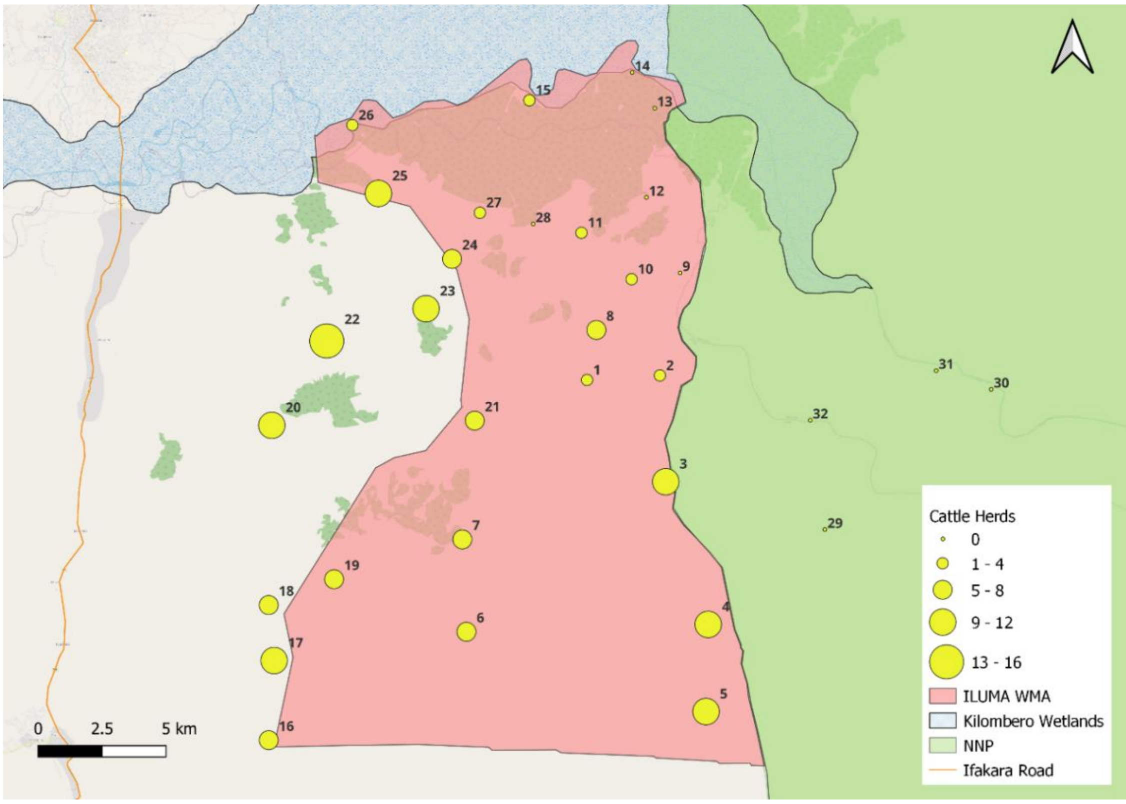

Figure 22. Map of ILUMA WMA displaying the average numbers of cattle herds detected per camp over the course of the study period.

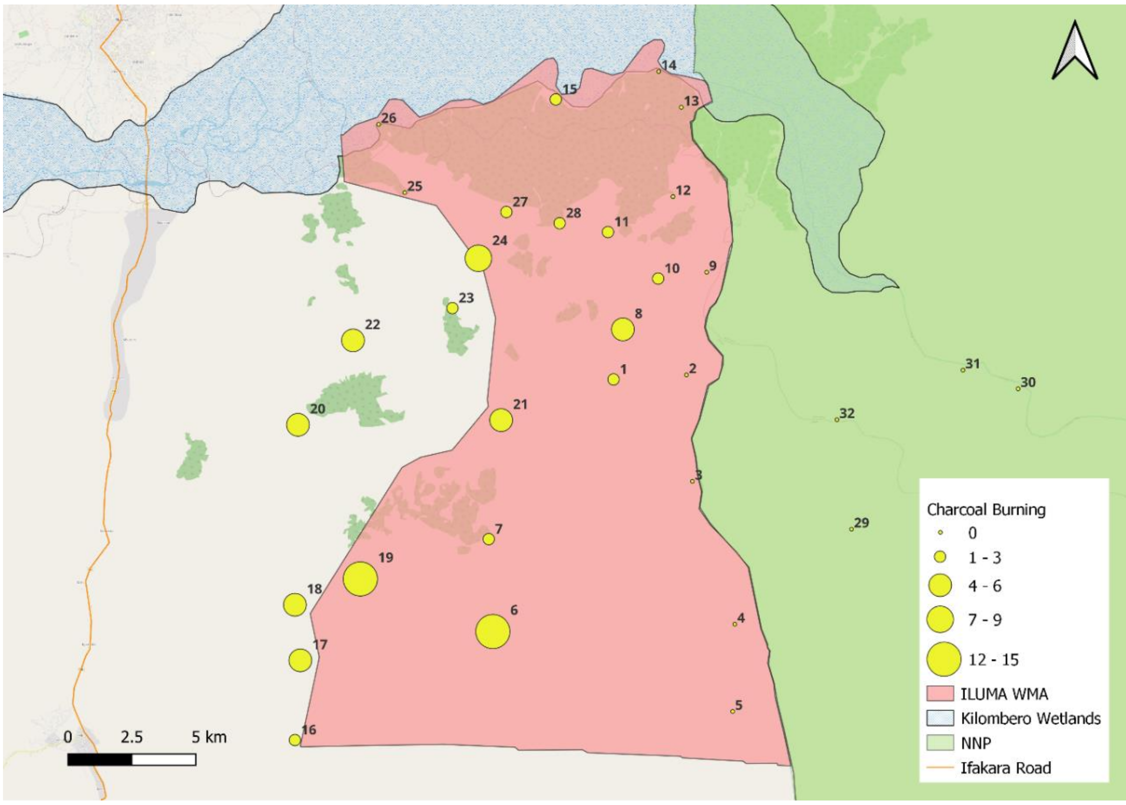

Figure 23. Map of ILUMA WMA displaying the average numbers of unauthorised charcoal burning occurrences detected per camp over the course of the study period.

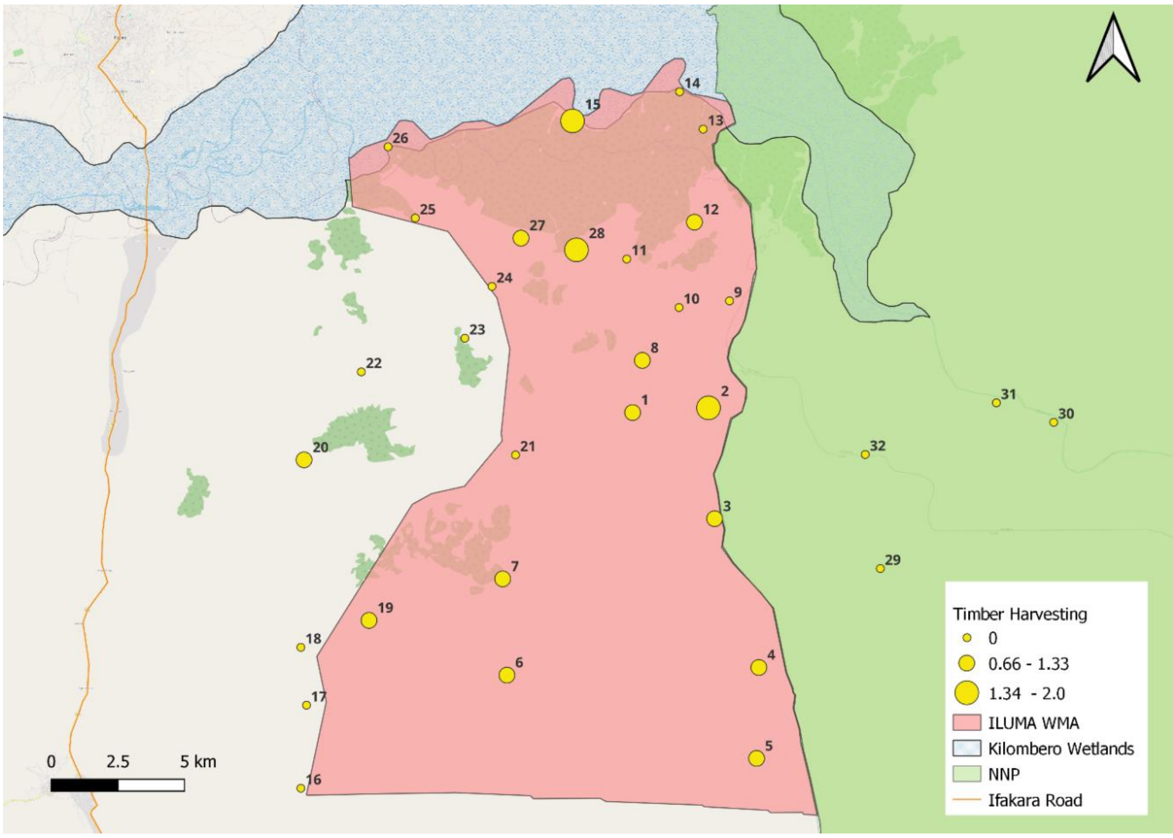

Figure 24. Map of ILUMA WMA displaying the average numbers of timber harvesting occurrences detected per camp over the course of the study period.

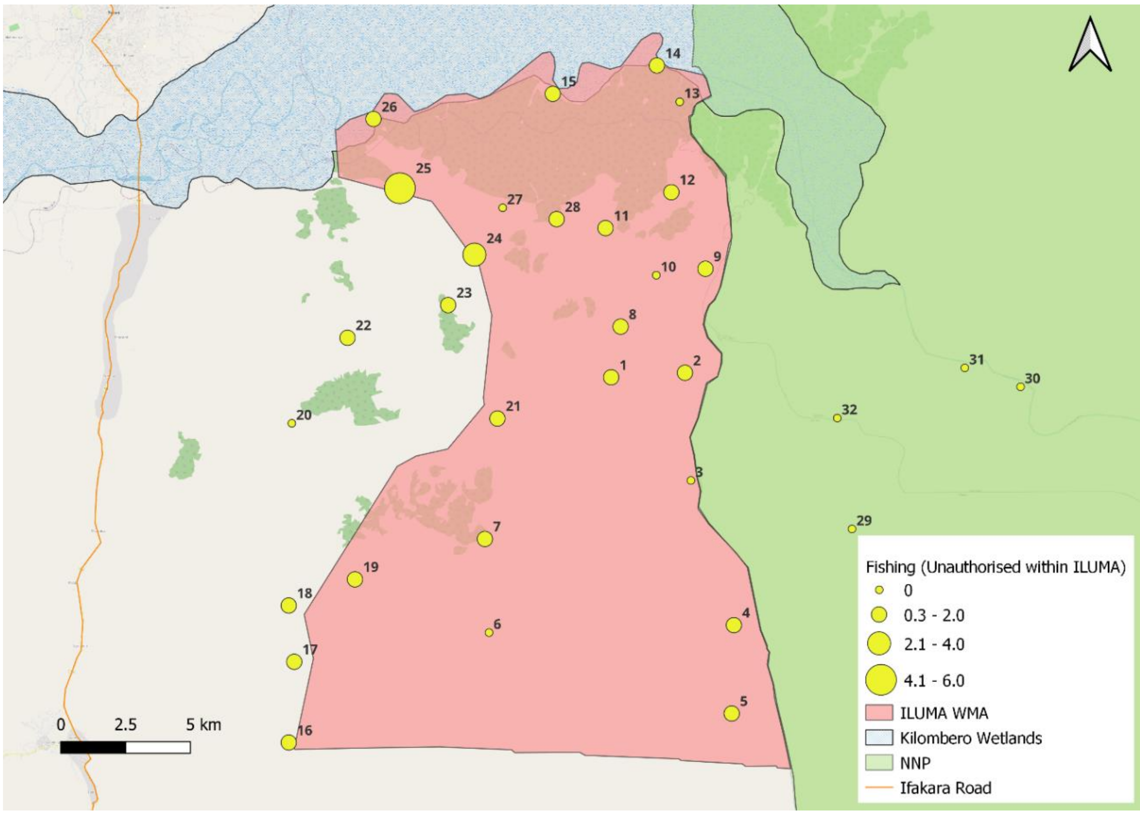

Figure 25. Map of ILUMA WMA displaying the average numbers of fishing (the fishing displayed on this map is unauthorised inside ILUMA WMA's boundaries) occurrences detected per camp over the course of the study period.

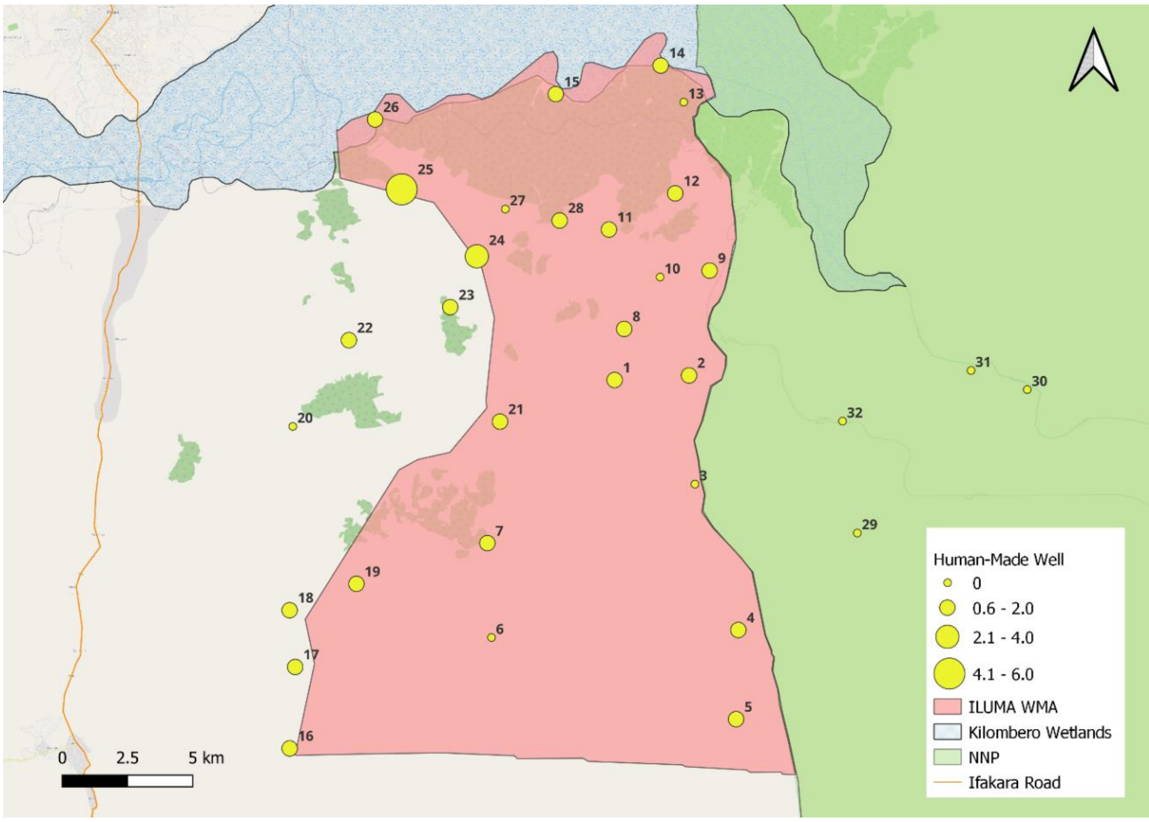

Figure 26. Map of ILUMA WMA displaying the average numbers of human – made wells detected per camp over the course of the study period. Note the similarity of distribution with human settlement.

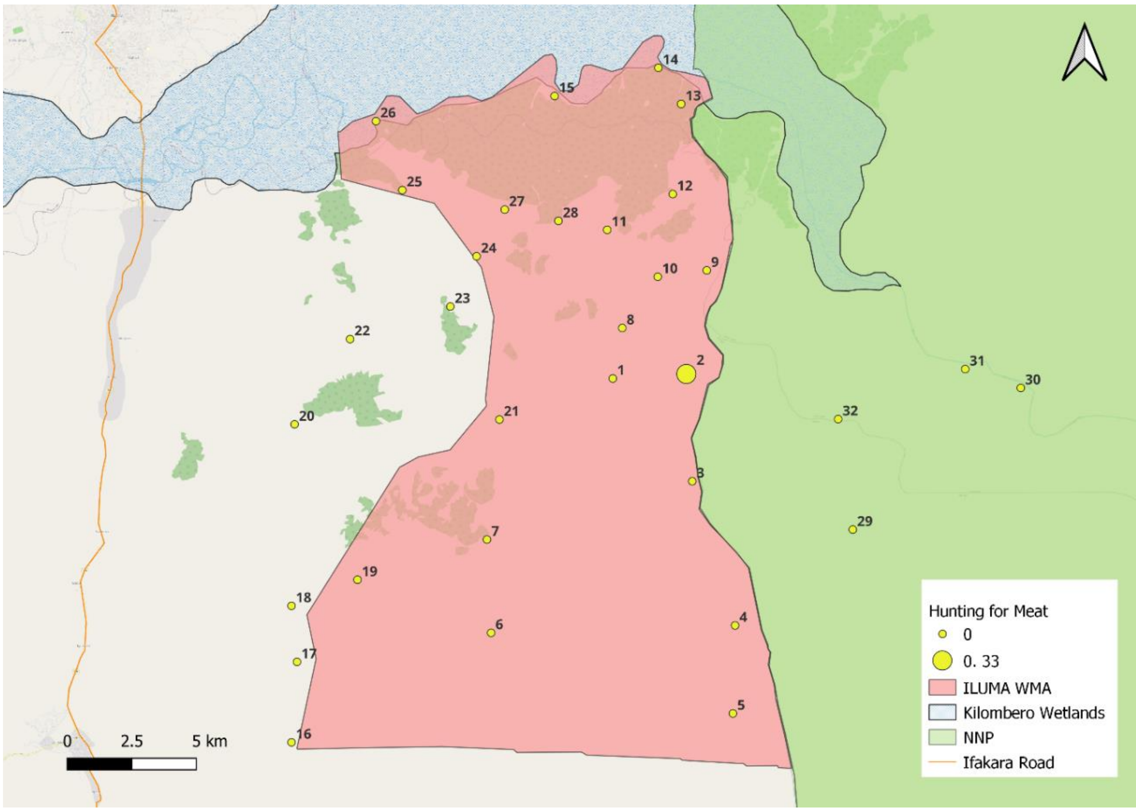

Figure 27. Map of ILUMA WMA displaying the average numbers of occurrences of unauthorised hunting for meat detected per camp over the course of the study period.

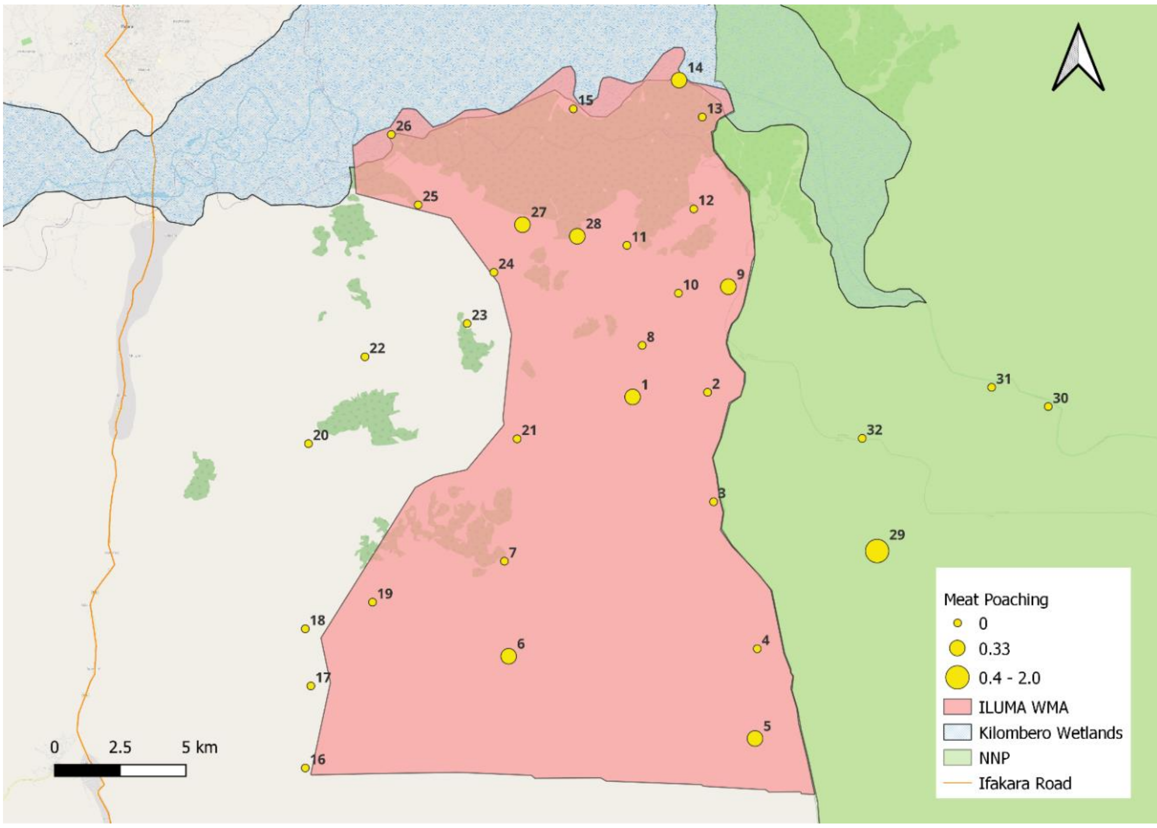

Figure 28. Map of ILUMA WMA displaying the average numbers of meat poaching occurrences detected per camp over the course of the study period.

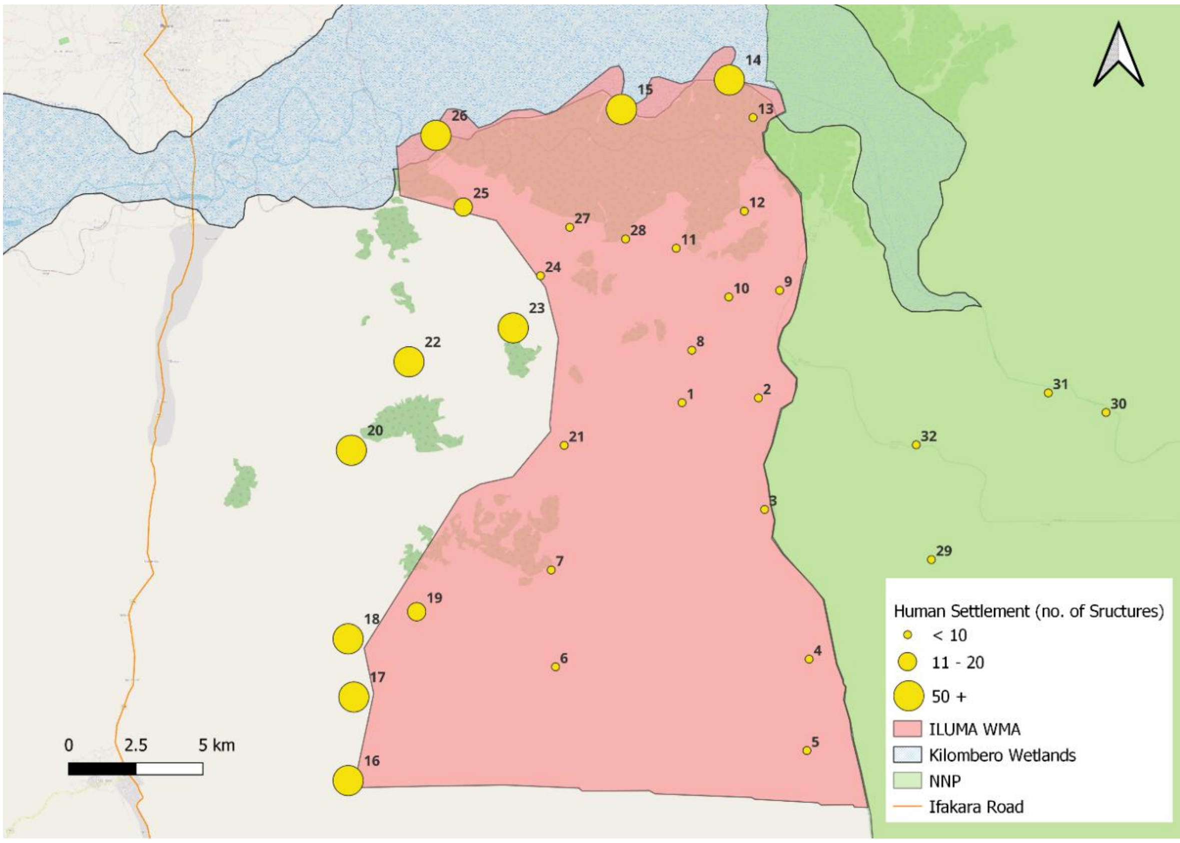

Figure 29. Map of ILUMA WMA displaying the average numbers of human settlement structures detected per camp over the course of the study period.

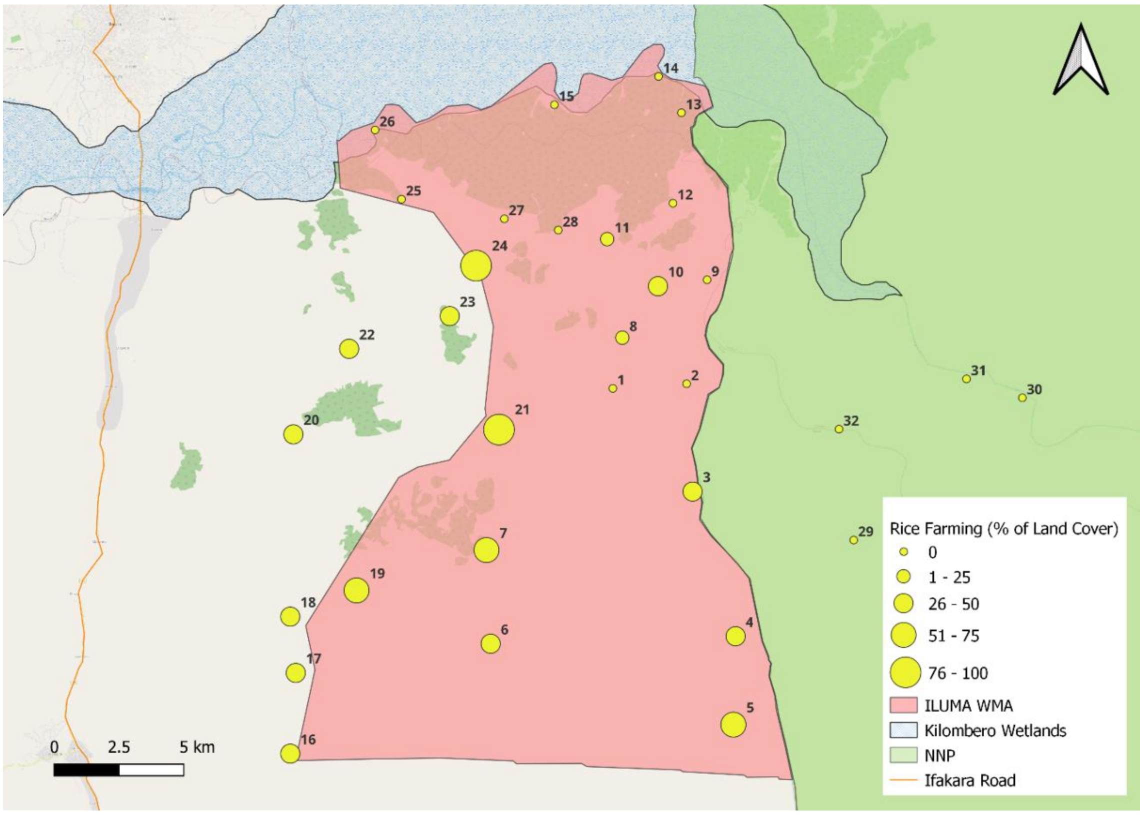

Figure 30. Map of ILUMA WMA displaying the average percentage of land covered in rice agriculture per camp over the course of the study period.

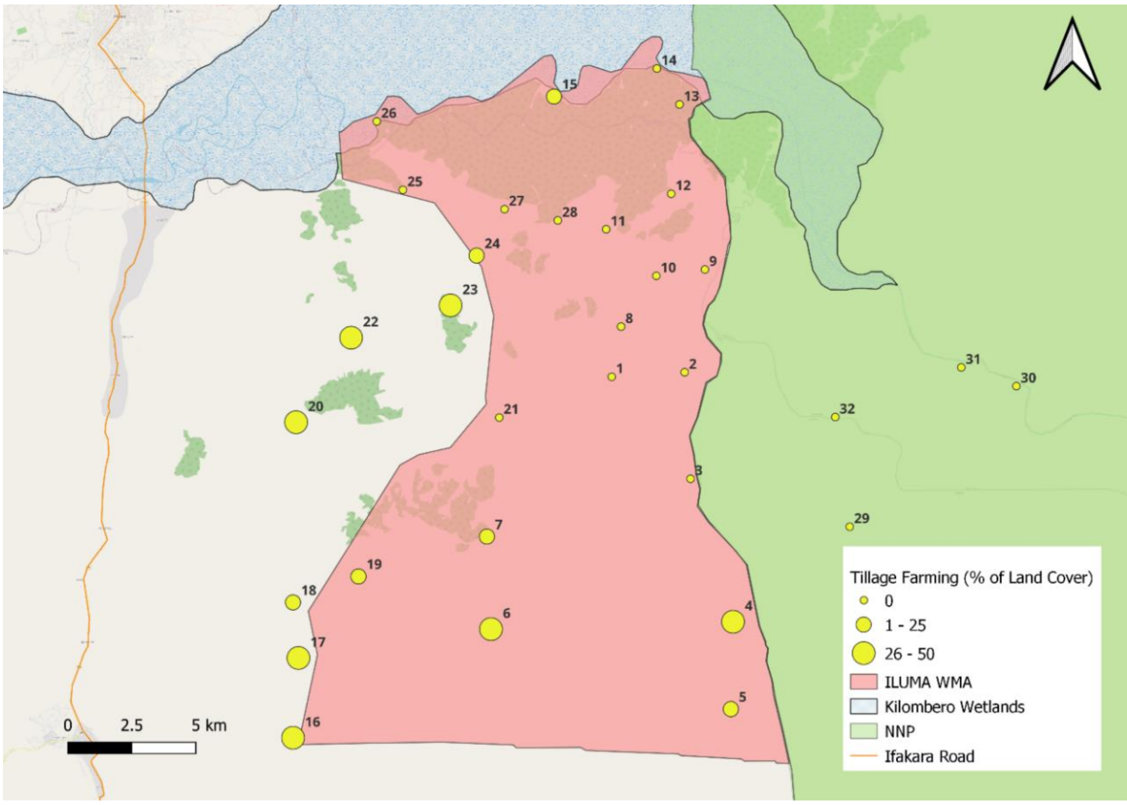

Figure 31. Map of ILUMA WMA displaying the average percentage of land covered in other tillage crop (not rice) agriculture per camp over the course of the study period.

3.2.3. Livestock and Work Animals.

Corresponding to the activity of cattle herding having such a high detection rate, the number of cattle composed the vast majority of all livestock recorded, with a total of over 950 herds detected (Figures 32A, 32B, 33A and 33B). Dogs were most frequently detected by tracks and were the next most common species of domesticated animals (Figure 32E and 33E). Sheep and goats were found in very small numbers and usually associated with a cattle herd. Poultry was found associated with human settlements only (see Appendix 1 and Figures 32 and 33).

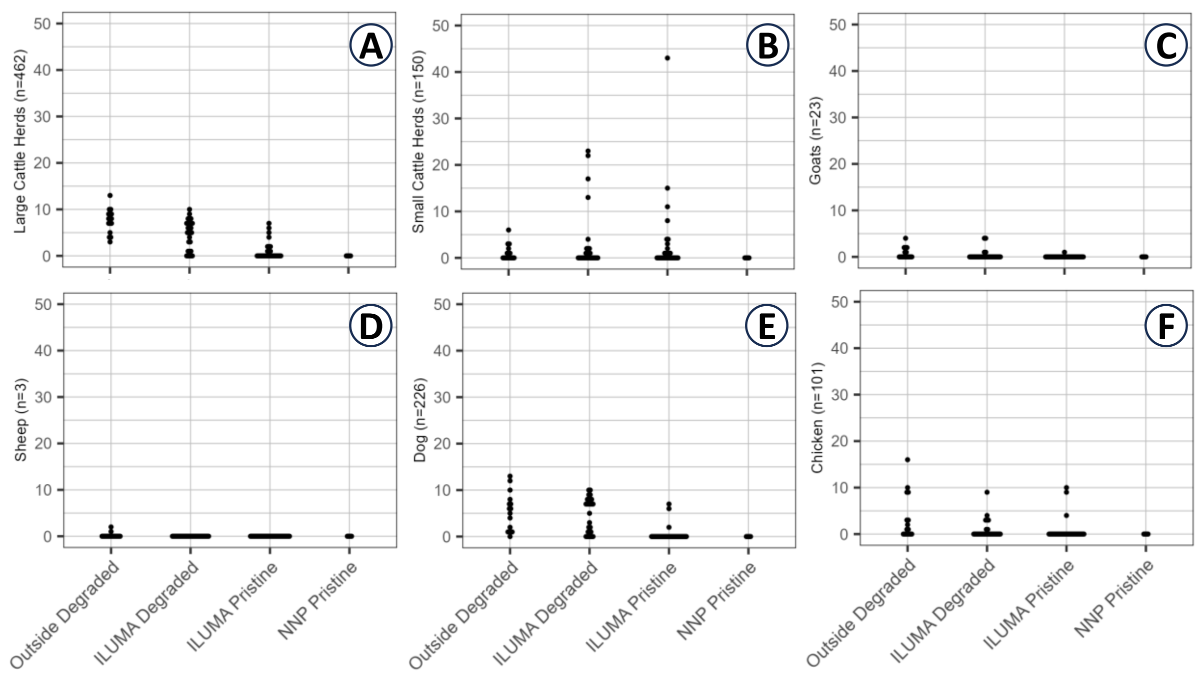

Figure 32. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of livestock and work animals detected in radial surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific livestock species was observed in that particular combination of detection type and location.

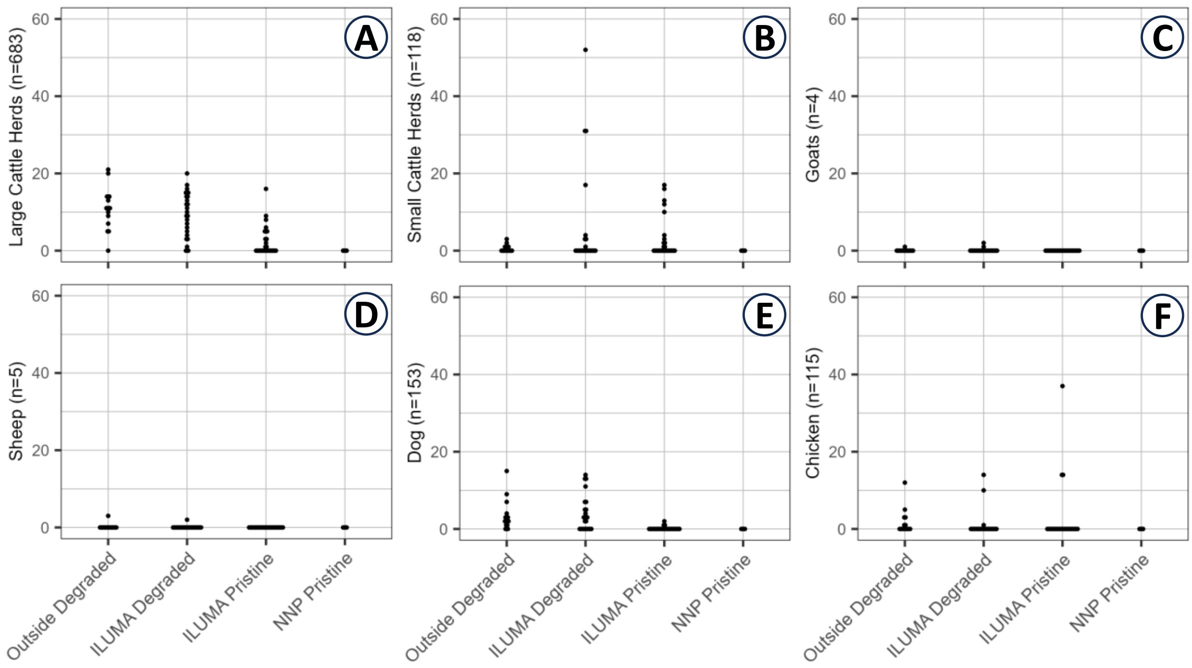

Figure 33. Dot plots summarising the total frequencies of direct observations, tracks, spoor, and other signs of livestock and work animals detected in transect surveys over the course of the study as detailed in Appendix 1. Each dot represents a unique record of data and is distributed based in the location of the camp in which it was recorded. Each dot corresponds to a value on the y-axis, which represents the number of times that specific livestock species was observed in that particular combination of detection type and location.

3.3. Comparative assessment of radial surveys and transect surveys.

The total cumulative results of all wildlife detections indicate that, whilst they require similar sampling effort, camp radial surveys and transect segment surveys yield quite different detection frequencies for different individual species (Appendix 1 and Figures 14, 15, 16 and 17). In terms of detecting raw presence/absence of species, in the given study environment, a waterbody-centred study (camp radial survey) is the better choice for 35 of 39 species and a statistically significantly better choice for 58% of species. This overall picture is summarised clearly in Figure 34. Of the thirty-nine species of wild herbivores, wild carnivores, wild rodents and wild primates and prosimians detected, the vast majority (89.74%) were more frequently detected in camp radial surveys. Wildebeest, side-striped jackal, slender mongoose, banded mongoose white-tailed mongoose, greater galago, vervet and giant cane rat all had fewer than 7 detections each, therefore a P-value was inestimable. Overall, this indicates that in the given study area, camp radial surveys permit more sensitive detection of most species than transect surveys of approximately the same duration. Indeed, eight species, specifically: puku, wildebeest, red duiker, side – striped jackal, slender mongoose, banded mongoose, vervet and giant cane rat were only detected by radial surveys. Furthermore, just 6.28% of all Bushpig detections were recorded during a transect surveys, and only 11.11% for suni, 11.48% for blue monkey and 15.58% for common duiker. Every species of wild carnivore was detected more frequently during camp radial surveys, except for spotted hyena, which travel large distances each night and are known to use paths like those followed by the investigators. Just four species: greater kudu, sable, spotted hyena and baboon were recorded more frequently during transect surveys than radial surveys (see Figure 34). Detections were approximately evenly distributed across survey types for only 3 species, specifically hartebeest, African civet, and genet, they were detected equally in both types of survey, with neither survey method providing significantly better detection rates. As the overall goal of this study was to document where human activities and wildlife overlap, and the subsequent consequences of those interactions across a range of different locations far enough apart to be reasonably considered statistically independent, Also, the study was designed to allow comparison across a heterogeneous landscape with very different land use practices and the greater sensitivity of radial surveys offer an obvious advantage, therefore analyses described from section *3.4* onwards exclusively rely on data for camp radial surveys only.

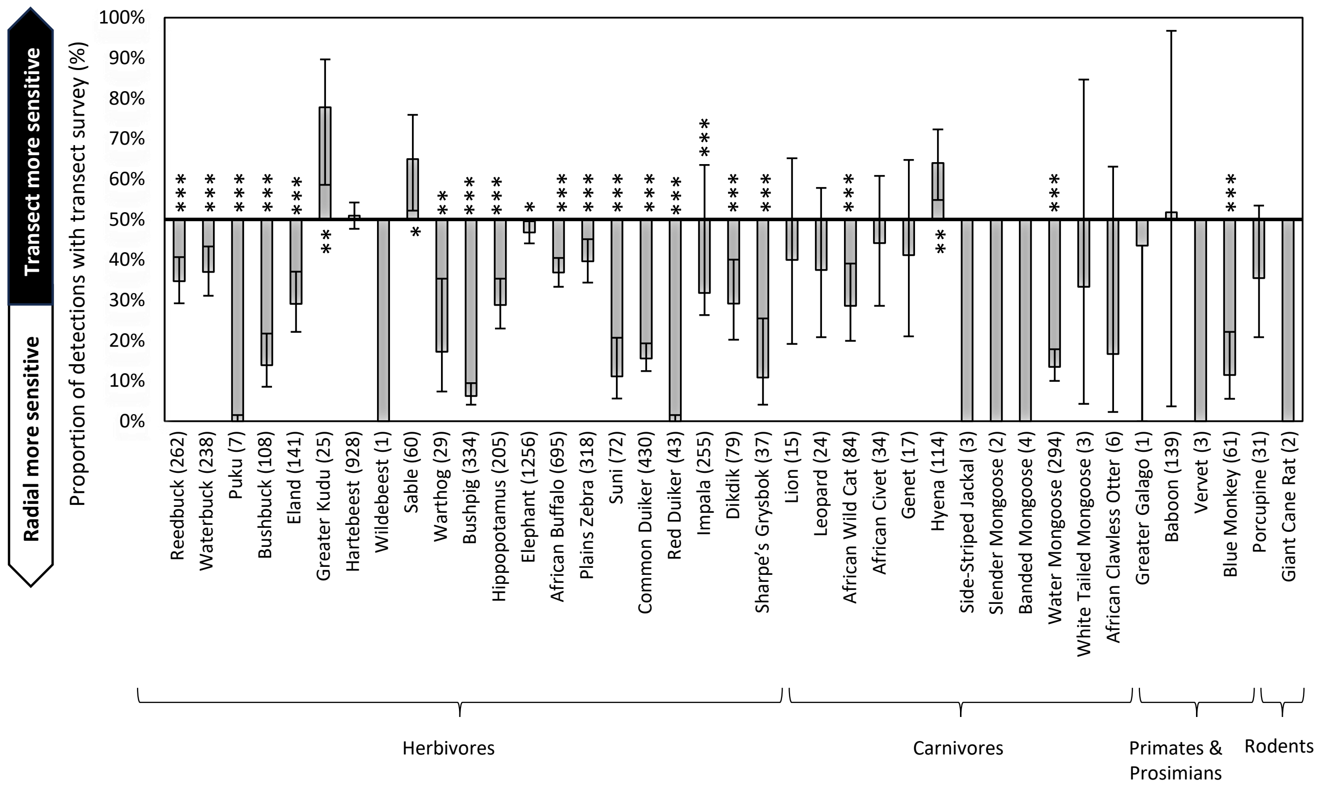

Figure 34. Bar chart with the horizontal axis centred at 50% null hypothesis of a binomial distribution illustrating the proportions of deviations of each species occurring during transect rather than radial surveys. In most cases the mean and 95% confidence intervals were estimates of a multivariate generalised linear model (GLM) analysis using a binomial distribution on total observations (direct sighting, tracks, spoor and other signs) recorded for each species in transect segment surveys as a proportion of total observations from both survey types (transect segment surveys and camp radial surveys). 95% confidence intervals are also provided. For species detected only on radial surveys, for which no confidence interval could be detected by GLM, the two-tailed probability of a one-sided distribution occurring was calculated as $P = 0.5^{n-1}$ where n is the number of times the species was detected. Species detected less than seven times ($n < 7$); confidence intervals are inestimable. *** $P < 0.001$, ** $P < 0.01$, * $P \leq 0.05$.

3.4. Indices of ecosystem integrity and animal community relative abundance and diversity.

3.4.1. Cluster Analysis.

Cluster analysis split the 32 camp locations into two equally sized, clearly distinguished groups composed of 16 camps in each (See figures 35 and 36, and Table 5 for details). Clustering was carried out using all recorded parameters for wildlife, human activities, livestock and landcover attributes, yielding a pattern that obviously divided the camps into groups based on their level of environmental degradation. This clear distribution is also reflected in the geographic distribution of the camps.

One cluster contains all of the village-based camps outside the western boarder of ILUMA that are fully domesticated, as well as the camps highly encroached inside ILUMA to the west and to the south. Within ILUMA, the following activities readily explain why almost every camp in the cluster is degraded and the cluster itself was interpreted as reflecting a *degraded* status. Extensive rice agriculture at camps 5, 7, 19, 21 and 24. Large areas of human settlement at camps 4, 5, 6, 7 and 25. Deforestation was recorded at camps 4, 7 19. Camp 15 is a legal fishing camp located on the northern most boundary. The exception in this cluster is camp 27 which showed little sign of encroachment.

In stark contrast, all the camps statistically attributed to the second cluster were better conserved, so this cluster was interpreted as reflecting a relatively pristine status. These *pristine* camps occur where ILUMA boarders NNP on the eastern side of ILUMA where there is less encroachment by humans and livestock and, and the north where the Kilombero river acts as a physical boundary encroachment. The cluster also includes the NNP camps to the east. While one of the *pristine* camps was beginning to experience encroachment (camp 9), another was regenerating from previous deforestation (camp 1), overall, the ecosystem of these locations was generally intact and in good condition.

Camps 12 and 13, both located in the northeast, were located in a dense, largely intact groundwater forest, and each close to a large waterhole. The areas within ILUMA that have authorised fishing camps (camps 14 and 26) as part of its agreed management plan represent informative exceptions to the general rule that human settlements are inevitably associated with habitat degradation. These fishing camps were well managed settlements that were confined to a very small geographical area with an authorised and carefully regulated sustainable livelihood (fishing) that has negligible impact on the adjacent terrestrial habitat. Consequently, the surrounding forest and floodplain are essentially intact with no sprawl of dwellings beyond the designated settlement limits, which ensures that the ecosystem bordering these fishing camps is intact and experiences very minimal unlawful human activities due to being monitored and patrolled frequently.

Overall, the patterns defined by the clustering are clear. There are no pristine camps outside the western boundary of ILUMA and there are no degraded camps inside NNP. ILUMA contains a mix of both degraded and pristine, but with more degraded camps located to the west and south of the area and more pristine camps located to the east and north (see Figure 36). Cluster analysis provided a clear separation in the locations sampled into two even groups, this was then analysed further using the five different indices that synthesise the same data in complementary ways and provided somewhat different but complementary results that yielded triangulated insights from different perspectives.

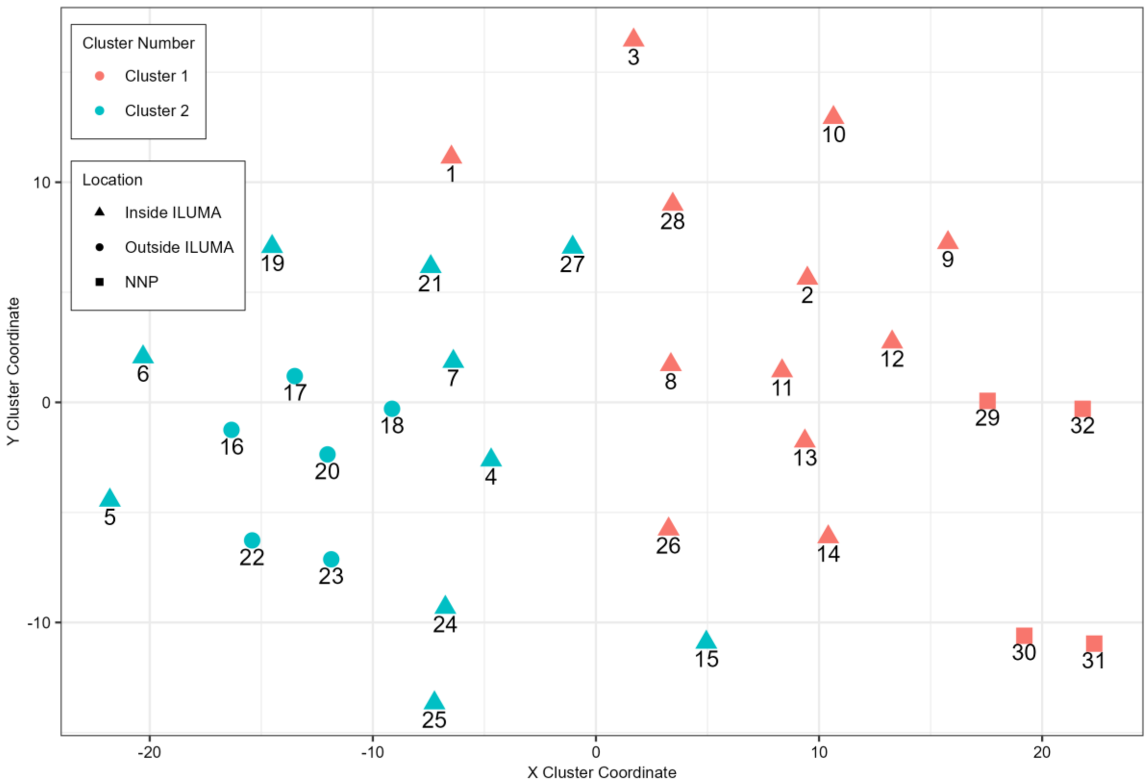

Figure 35. Results of cluster analysis on the 32 camp locations (numbered) showing the clear distinction between the two clusters, where colour represents cluster number and shape represents location inside ILUMA WMA, outside in the villages along its western boundary or inside NNP to the east.

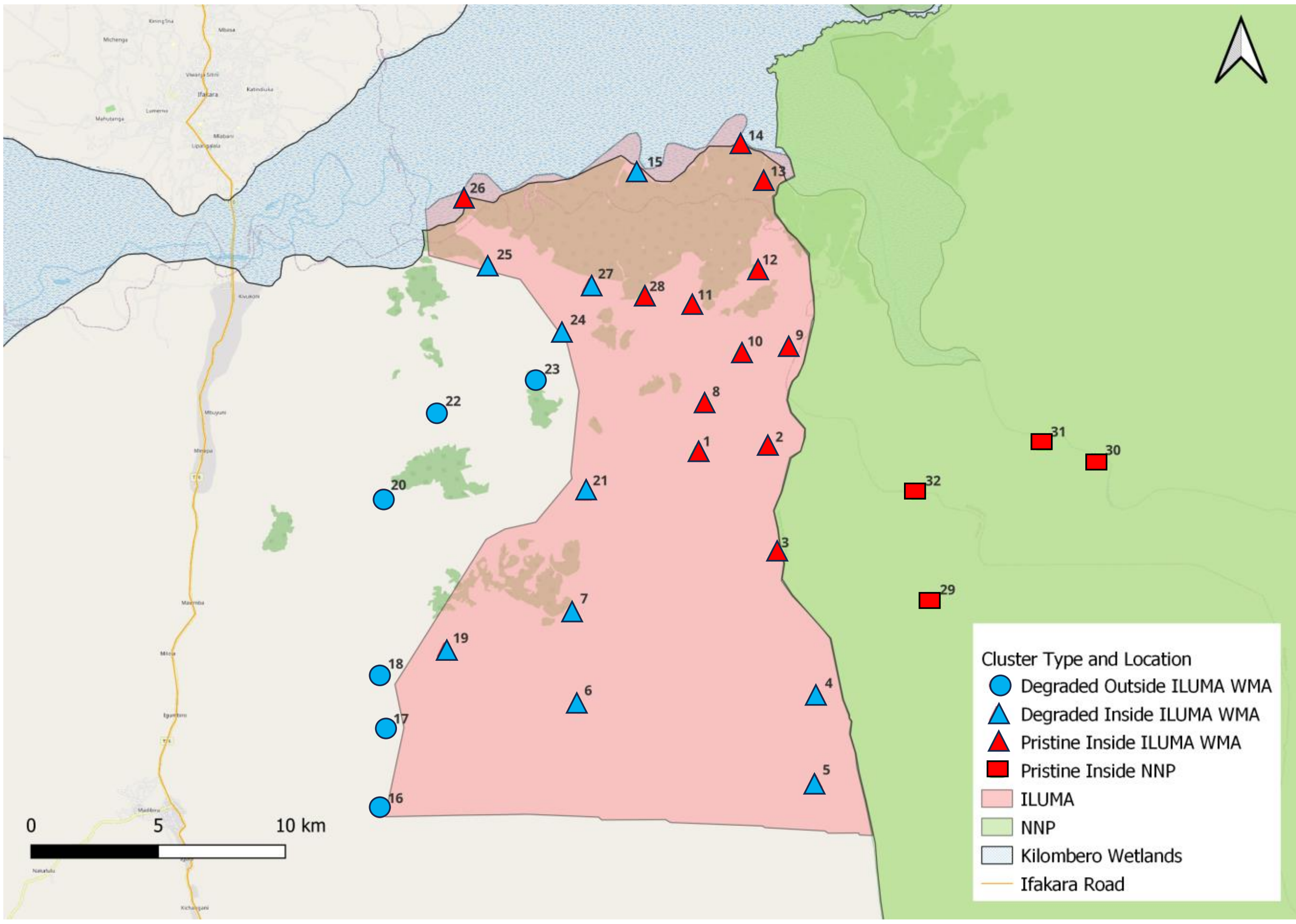

Figure 36. Map of ILUMA WMA displaying the 32 camp locations sampled. Where shape represents location inside ILUMA WMA, outside in the villages along its western boundary or inside NNP to the east and colour represents cluster type: *pristine* (red) or *degraded* (blue).

Table 5. Results of various ecological indices calculated for each location (camp). Cluster Analysis of all activities, entities, and land cover attributes. Species Richness of all recorded wildlife data. Simpson's Index of Diversity of all recorded wildlife data. Subjective, opinion-based Ecosystem Integrity Score. Natural Community Integrity Index based on PCA of all recorded parameters for all wildlife data. Natural Ecosystem Integrity Index PCA based index of all recorded parameters of humans, livestock, and wildlife.

Camp	Cluster[a]	Location	Historic Natural Land Cover	Species Richness Index[b]		Simpson's Index of Diversity[c]		Subjective Natural Ecosystem Integrity Index[d]		Objective Natural Animal Community Index[e]		Objective Natural Ecosystem Integrity Index[f]	
				Value	Rank[g]	Value	Rank[g]	Value	Rank[g]	Value	Rank[g]	Value	Rank[g]
1: Msakamba	Pristine	Inside ILUMA WMA	Miombo Woodland	16	6	0.952	4	70	17	-0.507	20	-0.390	14
2: Msiba wa Deo	Pristine	Inside ILUMA WMA	Miombo Woodland	20	2	0.934	12	84	9	0.338	6	-0.478	6
3: Bwawa la Nyati	Pristine	Inside ILUMA WMA	Miombo Woodland	17	5	0.957	1	85	8	0.250	8	-0.439	9
4: Bwawa la Nandete	Degraded	Inside ILUMA WMA	Miombo Woodland	16	6	0.956	2	35	23	-0.349	15	-0.370	17
5: Korongo la Bundu	Degraded	Inside ILUMA WMA	Miombo Woodland	18	4	0.951	5	30	24	-0.468	18	-0.352	20
6: Bwawa la Namamba	Degraded	Inside ILUMA WMA	Miombo Woodland	12	10	0.889	18	40	22	-0.619	28	-0.347	21
7: Bwawa la Chakacheni	Degraded	Inside ILUMA WMA	Miombo Woodland	6	13	0.652	26	15	26	-0.594	24	-0.333	25
8: Bwawa la Njuju	Pristine	Inside ILUMA WMA	Miombo Woodland	19	3	0.952	3	81	12	-0.169	12	-0.411	11
9: Bwawa la Chamvi	Pristine	Inside ILUMA WMA	Miombo Woodland	19	3	0.950	6	86	7	-0.004	10	-0.418	10
10: Bwawa la Miembeni	Pristine	Inside ILUMA WMA	Miombo Woodland	15	7	0.933	13	68	18	0.035	9	-0.443	8
11: Kisima cha Seba	Pristine	Inside ILUMA WMA	Miombo Woodland	9	12	0.882	19	82	11	-0.410	17	-0.369	18
12: Bwawa la Maya	Pristine	Inside ILUMA WMA	Miombo Woodland	22	1	0.928	14	87	6	0.296	7	-0.445	7
13: Bwawa la Mrope	Pristine	Inside ILUMA WMA	Groundwater Forest	12	10	0.893	17	90	5	-0.244	13	-0.383	15
14: Mikeregembe	Pristine	Inside ILUMA WMA	Groundwater Forest	17	5	0.947	9	75	15	-0.500	19	-0.382	16

15: Mdalangwila	Degraded	Inside ILUMA WMA	Groundwater Forest	22	1	0.941	10	72	16	-0.260	14	-0.399	13
16: Bwawa la Muamachi	Degraded	Outside ILUMA WMA	Miombo Woodland	4	15	0.574	27	6	28	-0.603	26	1.325	30
17: Tuliza Moyo	Degraded	Outside ILUMA WMA	Miombo Woodland	5	14	0.340	30	4	30	-0.581	23	1.082	28
18: Mavimba Porini	Degraded	Outside ILUMA WMA	Miombo Woodland	4	15	0.159	32	10	27	-0.568	22	0.065	26
19: Bwawa la Selessusi	Degraded	Outside ILUMA WMA	Miombo Woodland	11	11	0.740	25	25	25	-0.749	31	-0.337	24
20: Makingi	Degraded	Outside ILUMA WMA	Miombo Woodland	2	16	0.234	31	0	32	-0.597	25	1.185	29
21: Bwawa la Mpunga	Degraded	Inside ILUMA WMA	Miombo Woodland	12	10	0.785	23	55	19	-0.721	30	-0.344	22
22: Kisaki	Degraded	Outside ILUMA WMA	Miombo Woodland	5	14	0.411	29	5	29	-0.607	27	3.805	32
23: Uwanja wa Ndege	Degraded	Outside ILUMA WMA	Miombo Woodland	6	13	0.504	28	3	31	-0.621	29	2.781	31
24: Bwawa la Mkwajuni	Degraded	Inside ILUMA WMA	Miombo Woodland	11	11	0.841	21	45	21	-0.529	21	-0.340	23
25: Bwawa la Mamba Luhogi	Degraded	Inside ILUMA WMA	Miombo Woodland	15	7	0.836	22	48	20	-0.850	32	0.144	27
26: Funga	Pristine	Inside ILUMA WMA	Groundwater forest	13	9	0.754	24	77	14	-0.401	16	-0.366	19
27: Bwawa la Mlenda	Degraded	Inside ILUMA WMA	Miombo Woodland	15	7	0.879	20	83	10	-0.162	11	-0.408	12
28: Bwawa la Semka	Pristine	Inside ILUMA WMA	Miombo Woodland	16	6	0.928	15	80	13	0.587	5	-0.488	5
29: Bwawa la Simba	Pristine	Nyerere National Park	Groundwater Forest	11	11	0.910	16	97	3	2.356	3	-0.549	2
30: Kiboko Zanzibar	Pristine	Nyerere National Park	Acacia Savanna	16	6	0.935	11	100	1	2.920	1	-0.519	3
31: Zanzibar	Pristine	Nyerere National Park	Miombo Woodland	14	8	0.949	7	92	4	1.606	4	-0.489	4
32: Bwawa la Moto	Pristine	Nyerere National Park	Miombo Woodland	18	4	0.948	8	99	2	2.724	2	-0.590	1

[a] Interpreted results of a cluster analysis performed on every variable collected, including all human, livestock, and wildlife activity, as well as conditions such as ground type, vertical grass height and horizontal density of tree, bush and shrub cover. See sections *2.4.4.1* and *3.4.1* for details.

[b] Defined as *S* the sum of the total number of species recorded in a particular area (each camp). See sections *2.4.4.2* and *3.4.2* for details.

[c] Calculates the probability of selecting two individuals from different species within a defined area (camp) and calculated as SDI=1- D, where D = $\sum iPi^{2}$, where the species proportion(the proportion of a particular species divided by the total number of all species observations) (P_i) is calculated as $P_i = x_i/n$, where x_i is the total number of individuals of species i recorded and n is the total number of individuals from all species recorded. See sections *2.4.4.3* and *3.4.3* for details.
[d] Based on personal, subjective opinions of the three investigators based on their impressions over the time spent in the field, with each camp being given a consensus score from 0 to 100%, with 100% representing completely pristine conditions with no evidence of human activities and 0% representing highly degraded areas that have been completely converted into fully domesticated habitats. See sections 2.4.4.4 and 3.4.4 for details.
[e] Scaled results of Principal Component Analysis of all parameters recorded for wild herbivores, rodents, carnivores, primates, and prosimians. See sections *2.4.4.5* and *3.4.5* for details.
[f] Scaled results of Principal Component Analysis of all parameters recorded for human, livestock, and wild animals. See sections *2.4.4.6* and *3.4.6* for details.
[g] Locations ranked from the most species rich, biodiverse, or ecologically intact to the least, based on values from each index.

3.4.2. Species Richness Index (SRI).

The number of wild species recorded at each camp ranges from 2 (camp number 20 – *Makingi*) to 22 (camp number 12 – *Bwawa la Maya* and camp number 15 – *Mdalangwila*). This stark difference represents the wide range of species richness observed across the study area (see Figure 37 and Table 5). The camp at *Makingi* for example is in a fully domesticated settlement and is located the farthest of any camp outside of a protected area. *Bwawa la Maya* on the other hand, is located in the transition zone of groundwater forest and miombo woodland, and *Mdalangwila* is located adjacent to groundwater forest close to the border of NNP.

All of the top five ranked camps for species richness occur in the WMA rather than in the adjacent national park. This is likely due to the natural cover of the WMA consisting largely of miombo woodland and groundwater forest habitats which appears to host to a larger diversity of species than the acacia savanna habitat that dominates most of the camps sampled in NNP. This also corroborates information provided by VGS that the wildlife using NNP move through ILUMA seasonally, so it acts as an effective buffer zone between the national park and fully domesticated village habitats.

Of the top ten camps for species richness, two, namely the fishing camps of *Mdalangwila* and *Mikeregembe* (with 22 and 17 species respectively), are authorised human settlements within the WMA. Given that the surveys took place with the settlements acting as an anchor point for the two-kilometre radii used to define their limits, it is evident here that well-managed human settlements deep in the heart of a WMA can have an innocuous or even beneficial effect on species richness. These areas exhibited little evidence of cattle herding, which was the human activity with the largest negative impact on species richness, as explained in section *4.1.1.* The areas where cattle herding is highest was in and around the villages outside of ILUMA and in the degraded areas nearby, inside its boundaries. The habitat types of three of the five top ranked camps for species richness are classified as miombo woodland and the other two were groundwater forest, both of which provide a diverse ecosystem for a multitude of species. Of the camps ranked in the bottom ten, six are located outside of ILUMA. The trend that was noted in cluster analysis (section *3.1.6.*) whereby there is a gradient of abruptly increasing ecological integrity moving from west to east of the study area doesn’t exactly match with the trend noted in SRI, as the most pristine camps do not display the best SRI scores. This further strengthens the rationale for using multiple indices and methods which are useful when attempting to assess the ecological integrity of an area.

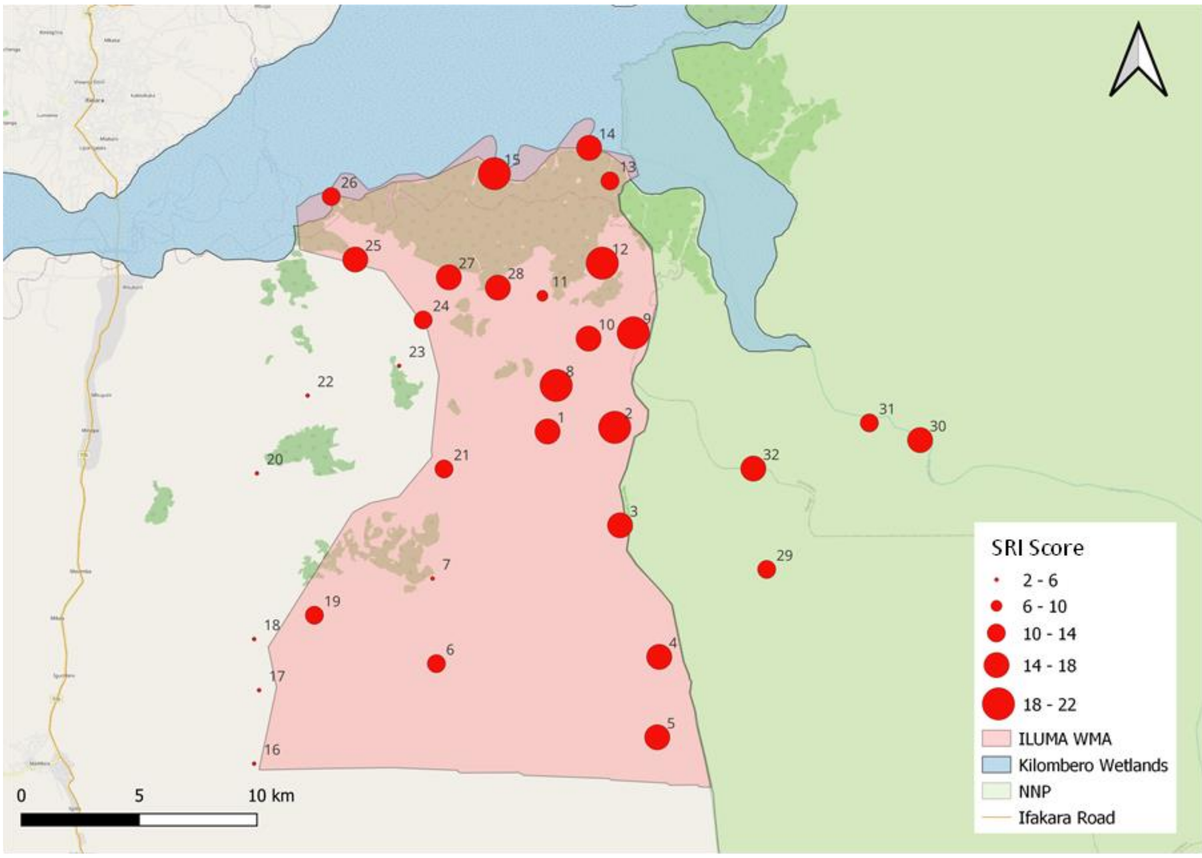

Figure 37. Map of ILUMA WMA, displaying the Species Richness Index (SRI) score awarded to each camp by analysis carried out in section 2.4.4.2. Score is signified by dot size, where larger dot equates to higher score.

3.4.3. Simpson’s Index of Diversity (SID).

The range of SID values calculated for each of these camps for this index varied widely. The most diverse camp *Bwawa la Nyati* had a score of 0.96, while the least diverse camp, *Mavimba Porini* scored 0.16. Exactly half of the camps have a SID score >0.90, which confirms that the better conserved areas of the WMA are highly species diverse. Although it may be expected that an area with higher levels of wildlife protection, like nearby NNP, would have greater levels of species diversity than those held to less strict standards, which permit human habitation in limited amounts and act as a buffer zone between a highly protected area and a fully domesticated environment such as WMAs, this index provides evidence to the contrary.

Of the top five camps in terms of SID, all are located inside ILUMA in locations with Miombo woodland land cover. It is important to highlight, however, that two of these camps (camps 4 and 5) are classified as degraded and were experiencing an increase in encroachment by both human settlement and rice agriculture at the time. While the camps located inside NNP did yield high SID scores (all > 0.90), when ranked amongst the other locations sampled, none of them were ranked in the top 5 (ranked 7, 8, 11 and 16). This result displays that even a degraded miombo woodland ecosystem can support a greater diversity of species than a well-protected, non-encroached acacia savanna (see Figure 38).

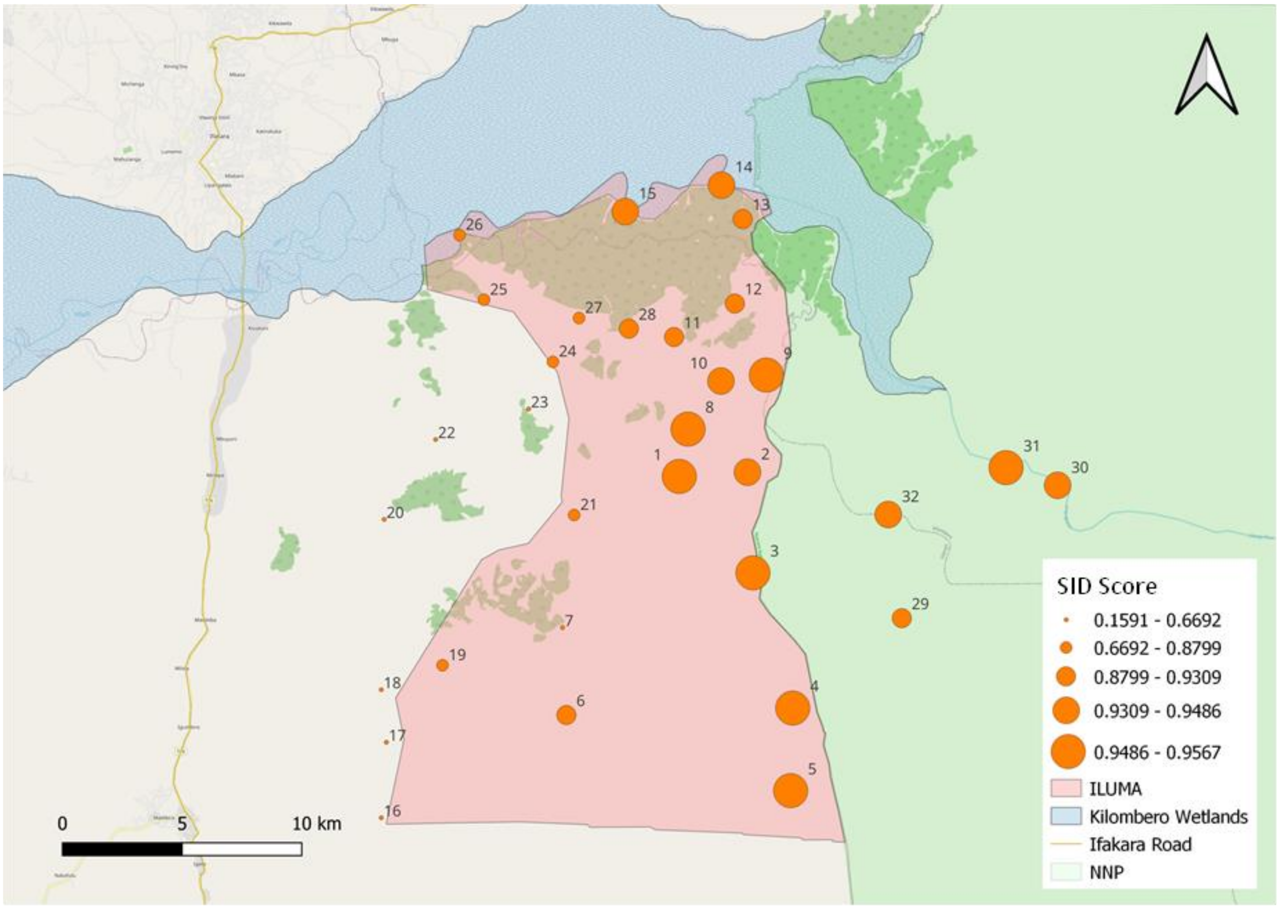

Figure 38. Map of ILUMA WMA, displaying the Simpson's Index of Diversity (SID) score awarded to each camp by analysis carried out in section 2.4.4.3. Score is signified by dot size, where larger dot equates to higher score.

3.4.4. Subjective Natural Ecosystem Integrity Index (SNEII).

The results of this score are primarily based on the perceived intactness of the ecosystem surrounding a camp based on the subjective impressions of the investigators. Therefore, areas that have human settlement, agriculture, and land clearing score worse than those that showed little to no sign of human disturbance. It is unsurprising that the four camps sampled in NNP were the camps with the highest score for this index, as they are afforded the degree of protection of national park status. Of the top 13 camps scored for SNEII, nine were camps outside of NNP and all scored 80 or greater. This shows clearly that in areas where ILUMA is well protected, human disturbance remains low and the ecosystem is largely intact. The opposite of this occurs however, in areas close the ILUMA's western border and in the villages outside of its western boundary. All six of the villages surveyed in this study (camps 16, 17, 18, 20, 22 and 23) received the lowest scores (≤10). A large reason for this was the sheer area of land that was cleared and/or highly degraded in the area surrounding the settlement, and the human activities that are associated with the settlement notably agriculture and livestock herding.

However, as can be seen from the high scores of the fishing camps settlements within ILUMA (camps 14, 15 and 26), human settlement alone does not necessarily result in a low SNEII score (75, 72 and 77 respectively). It is the specific livelihood associated activities like livestock herding, charcoal burning, timber harvesting, and both rice and other tillage agriculture that seem to be associated with a lower the score (see figure 39). The other camps inside ILUMA that scored low on this index all experience human encroachment to a certain degree. For example, camps 7 and 15 both have extensive rice agriculture, while 7 also had human settlement.

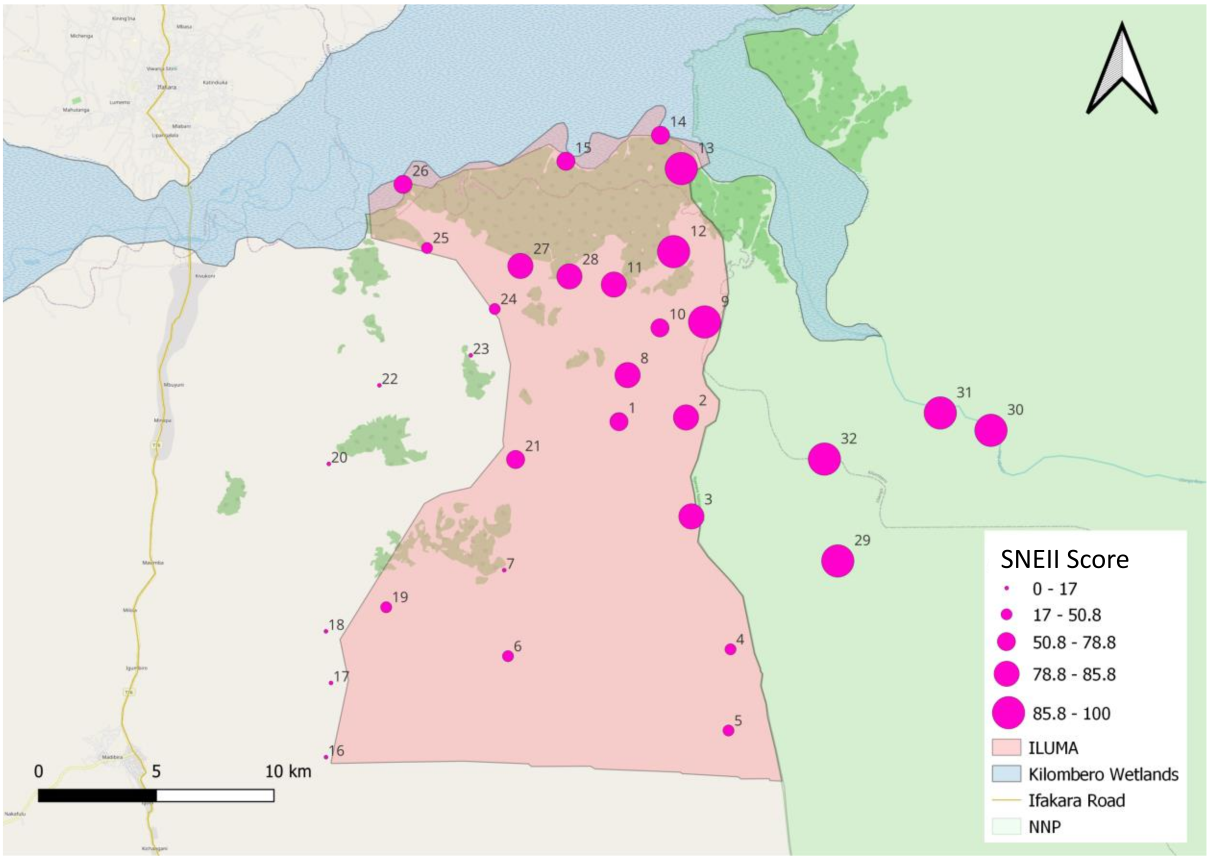

Figure 39. Map of ILUMA WMA, displaying the Subjective Natural Ecosystem Integrity Index (SNEII) score awarded to each camp by analysis carried out in section 2.4.4.4. Score is signified by dot size, where larger dot equates to higher score.

3.4.5. Objective Natural Animal Community Integrity Index (ONACII).

The top ranked camps in terms of ONACII are again the four NNP camps, in the exact same order as they were ranked by SNEII. Livestock herding was never recorded at these locations and meat poaching at one location only. The five worst ranked camps all contain large areas of human settlement where extensive human activities were ongoing. This index differs from the previous three, however, in that two of the village camps located outside ILUMA which were ranked towards the bottom of the list based on SRI, SID and SNEII, received a slightly improved score. Camps 18 and 20 received ranks of 22 and 25 respectively, which is an improvement from their rankings in other indices. This also demonstrates that some of the highly degraded camps within ILUMA, have scored worse than the legal settlements outside its boundaries. For example, camp 6 is ranked 28 of 32 camps, scoring worse than some villages, although it is well inside the southwestern boundary of the WMA (see Figure 40). This camp was adjacent to large areas of human settlement at the time and had become quite badly degraded. Also, extensive rice agriculture was recorded at camp 21, and its ONACII rank of 30 appears to reflect the resulting poor state of its natural community of wild herbivores, wild carnivores, wild primates, and prosimians.

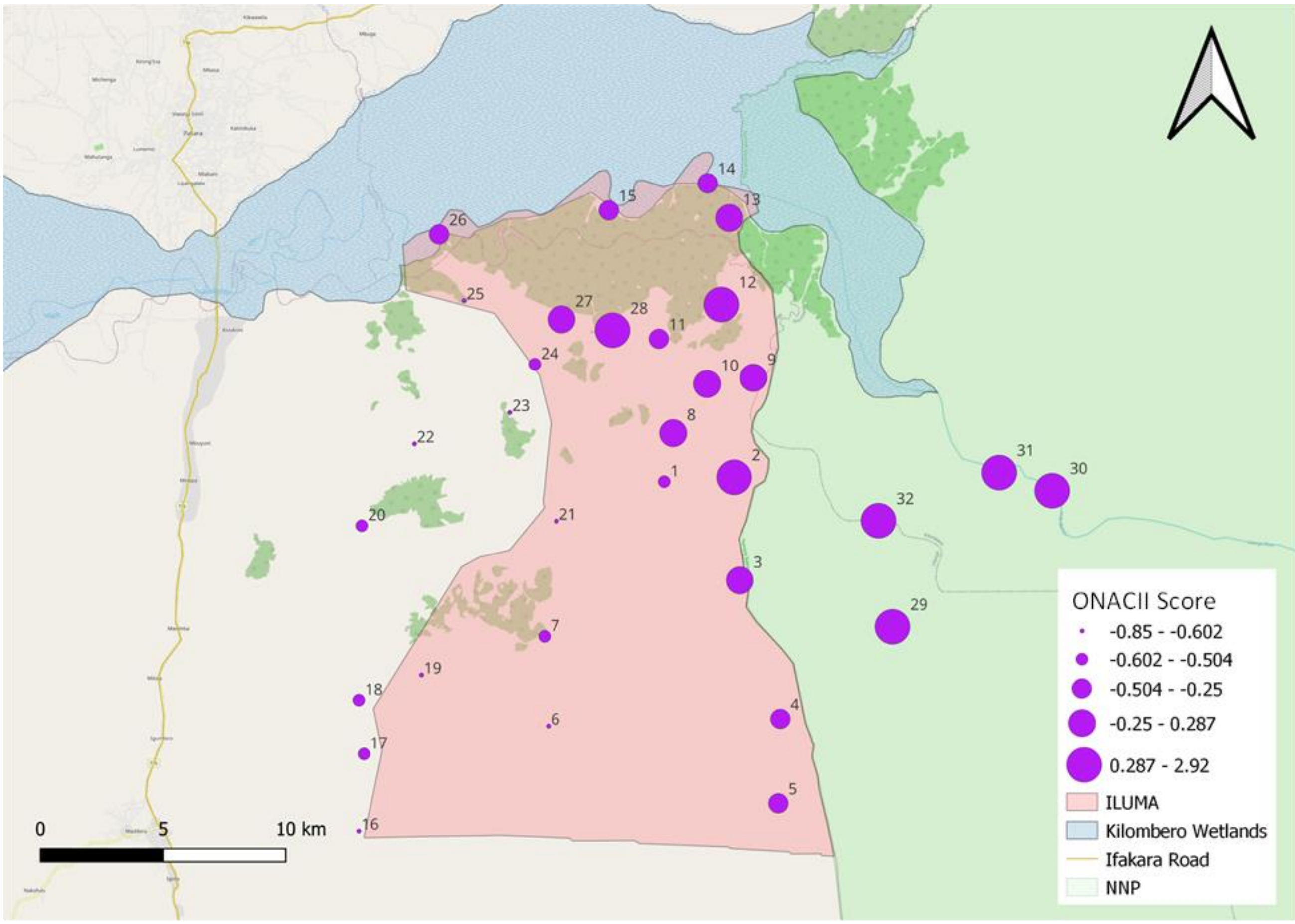

Figure 40. Map of ILUMA WMA, displaying the Objective Natural Animal Community Integrity Index (ONACII) score awarded to each camp by analysis carried out in section 2.4.4.5. Score is signified by dot size, where larger dot equates to higher score.

3.4.6. Objective Natural Ecosystem Integrity Index (ONEII).

This index takes all recorded parameters into account when producing a value for each camp as outlined in section *2.4.4.6*. of the methodology. The top ten scoring camps were all located either inside NNP (all ranked in the top 4) or in the northeastern section of ILUMA, very close to the border of the national park (camps 28, 2, 12, 10, 3 and 9). Because environmental factors such as tree and bush cover, as well as grass and forb height and ground type were factored into this index, this may be the cause of this locational grouping. However, within these ten camps, three are acacia savanna and one is groundwater forest and the remaining six are miombo woodland. Thus, although they are in close proximity geographically, the camps differ in natural land cover type. The location of these camps is also in the least degraded section of ILUMA and all fall within the *pristine* class as identified by cluster analysis. Therefore, they experience little human activity, encroachment, and degradation of land by unregulated expansion. The three fishing camps located inside ILUMA have been mid-ranked on this index and have received a similar score to camps like *Msakamba* (camp 1), which was steadily recovering from previous deforestation at the time. Overall, this index produced a similar ranking to SNEII and ONACII but with some noticeable differences (see Figure 41).

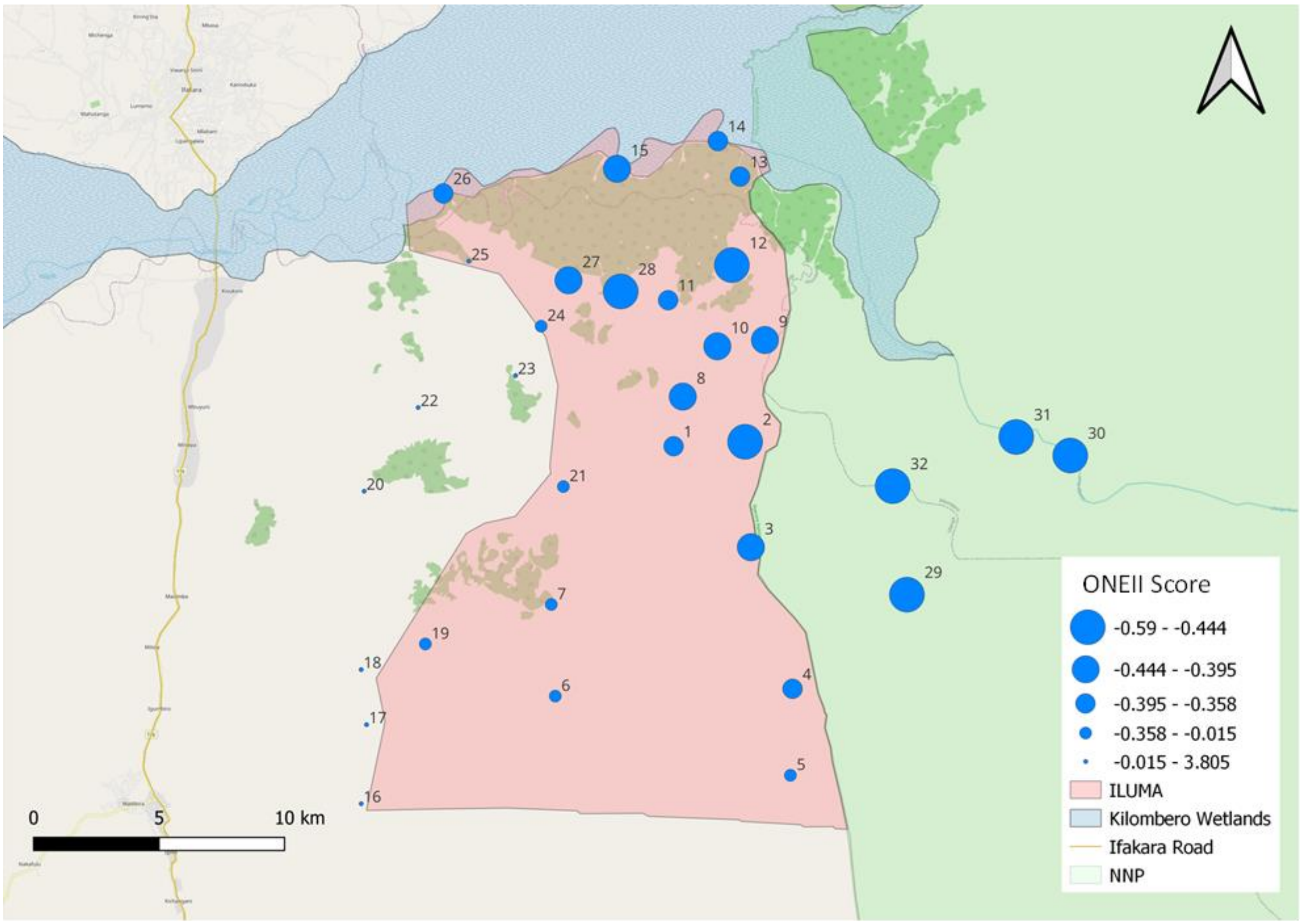

Figure 41. Map of ILUMA WMA, displaying the Objective Natural Ecosystem Integrity Index (ONEII) score awarded to each camp by analysis carried out in section 2.4.4.6. Score is signified by dot size, where larger dot equates to a lower score, lower indicates more pristine in this index.

3.5. Triangulation of cluster analysis against synthetic indicators of natural ecosystems.

Cluster analysis aided in visualising the various animal community and ecological indices by combining with geographic location to split the study area into four distinct areas: *degraded* outside ILUMA, *degraded* inside ILUMA, *pristine* inside ILUMA, *pristine* inside NNP. All five animal community and ecological integrity indices show a clear positive trend as the location moves from outside ILUMA WMA in the villages, through the WMA and into NNP and as the cluster status changes from *degraded* to *pristine*. SID and SNEII show the greatest change as the location and cluster number change, see Figure 42, panels B and C. SRI (Figure 42, panel A) and ONACII (Figure 42, panel D) also follow this trend, but it is less stark than the aforementioned indices. ONEII shows only a slightly better score as location and cluster status improves (Figure 42, panel E), but the increments of this index are far smaller than the others. Therefore, while each of the indices individually offer insights into different ecological perspectives of the study area, they all show a clear trend in increasing animal community and ecological integrity as the status of protection of the land increases and the level of degradation decreases.

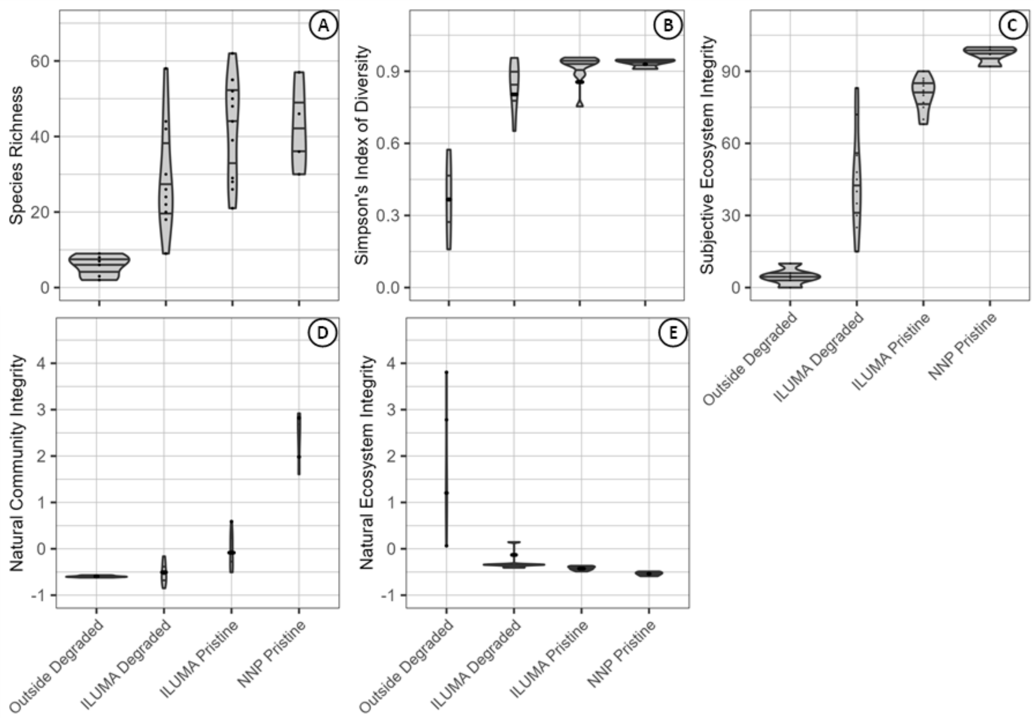

Figure 42. Dot and violin plots of ecological indices displayed in table 3: SRI (A), SID (B), SNEII (C), ONACII (D) and ONEII (E), based on their location in the study area and assigned cluster.

3.6. Comparison of novel Subjective Natural Ecosystem Integrity Index (SNEII) and statistically objective- PCA based Objective Natural Ecosystem Integrity Index (ONEII).

When comparing SNEII and ONEII it is important to note that the scores for ONEII run from positive to negative, with the most negative value representing the highest ranked camp. Although only two of the camps have been awarded the exact same rank by the two indices, most ranks are within a few places of each other. The results of a Spearman's ranked correlation test ($\rho = 0.902$, $p < 0.0001$) show that these indices with very similar intended purposes, are highly correlated (see Figure 43). Therefore, SNEII appears to be a reasonable, convenient, holistic and cost-effective substitute for ONEII which relies on detailed analyses of large amounts of labour-intensive data collection.

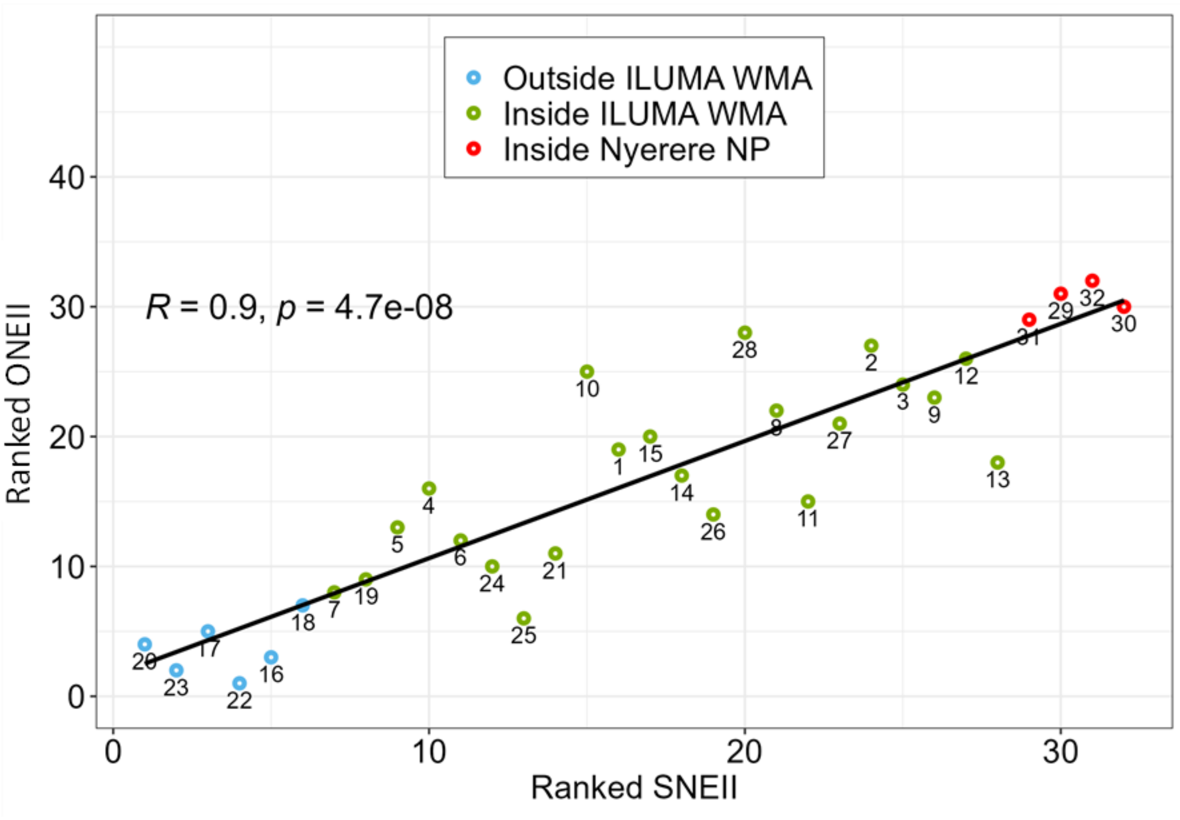

Figure 43. Correlation plot between SNEII and ONEII displaying a significant correlation and a Spearman's ρ value of 0.9. Each point represents a camp (numbered), and colour denotes its location.

3.7. Impact of human activities on indices of ecosystem integrity and animal community relative abundance and diversity.

Here, all the previously analysed human activities as described in sections *3.2.2.* are now evaluated as potential predictors of the integrity of natural animal communities and the ecosystems that support them, in order to evaluate the influence of community defined land use plans and de facto land use practices on wild populations of large mammals in the study area. In all cases single explanatory variable analyses indicated a number of human activities were associated with variation of the index in question, but only a small subset proved significant and were retained in the subsequent final multiple explanatory variables model.

3.7.1. Species Richness.

Livestock herding, charcoal burning, timber harvesting, hunting, the presence of wells, rice farming and farming of other tillage crops all had a significant effect on species richness in single explanatory variable analyses. However, as detailed in Table 6 and illustrated in Figure 44, the only human activity that remained significant in multiple explanatory variables analysis was livestock herding. Note the models detailed in Table 6 all had inverse link functions, so the positive parameter estimates actually reflect associations with reduced SRI.

Table 6. Results of single and multiple explanatory variable(s) linear regression analyses of scaled human activity indicators as determinants of the estimated Species Richness Index (SRI) for each camp surveyed, with statistically significant associations highlighted in bold. The best fit models identified for this SRI outcome assumed a Gaussian distribution and inverse link function for the dependent variable, so positive values therefore indicate a negative association between the independent and dependent variable.

	Single Independent Variable			Multiple Independent Variables		
Activity	β ± SEM	t	P	β ± SEM	t	P
Livestock Herding	**0.0186 ± 0.0056**	**3.348**	**0.0022**	**0.0186 ± 0.0056**	**3.348**	**0.0022**[a]
Charcoal Burning	**0.0273 ± 0.0115**	**2.381**	**0.0238**	0.0038 ± 0.0047	0.806	0.4271[b]
Timber Harvesting	**0.0049 ± 0.0018**	**2.636**	**0.0132**	0.0016 ± 0.0010	1.508	0.1425[b]
Fishing	0.0000 ± 0.0034	-0.008	0.9940	0.0046 ± 0.0028	1.649	0.1099[b]
Hunting	**0.0030 ± 0.0010**	**2.923**	**0.0065**	0.0010 ± 0.0007	1.504	0.1434[b]
Human Settlement	0.0150 ± 0.0080	1.871	0.0712	0.0017 ± 0.0060	0.278	0.7830[b]

Well	**0.0376 ± 0.0143**	**2.634**	**0.0132**	-0.0026 ± 0.0065	-0.404	0.6890[b]
Meat Poaching	0.0009 ± 0.0026	0.336	0.7390	-0.0015 ± 0.0018	-0.825	0.4160[b]
Human Presence	0.0667 ± 0.0508	1.314	0.1989	0.0657 ± 0.0633	1.037	0.3083[b]
Rice Farming	**0.0117 ± 0.0040**	**2.940**	**0.0063**	0.0031 ± 0.0030	1.031	0.3111[b]
Other Tillage Farming	**0.0132 ± 0.0051**	**2.587**	**0.0148**	0.0033 ± 0.0043	0.759	0.4543[b]

SD: Standard deviation of the coefficient point estimate.
P: P – Value.
[a] As estimated from the final, most parsimonious best-fit GLM, in which this was included on the basis of either being a significant ($P \leq 0.05$) determinant of SRI or approached significance ($P \leq 0.10$) as a determinant of SRI and significantly ($P \leq 0.05$) improved the goodness of fit based on the estimated Akaike Information Criterion (AIC).
[b] As estimated from the last GLM in which this variable was still included before being removed on the basis that it was not a significant determinant of the SRI ($P > 0.05$) or approached significance ($P \leq 0.10$) but did not significantly improve the goodness of fit based on the estimated AIC ($P > 0.05$).

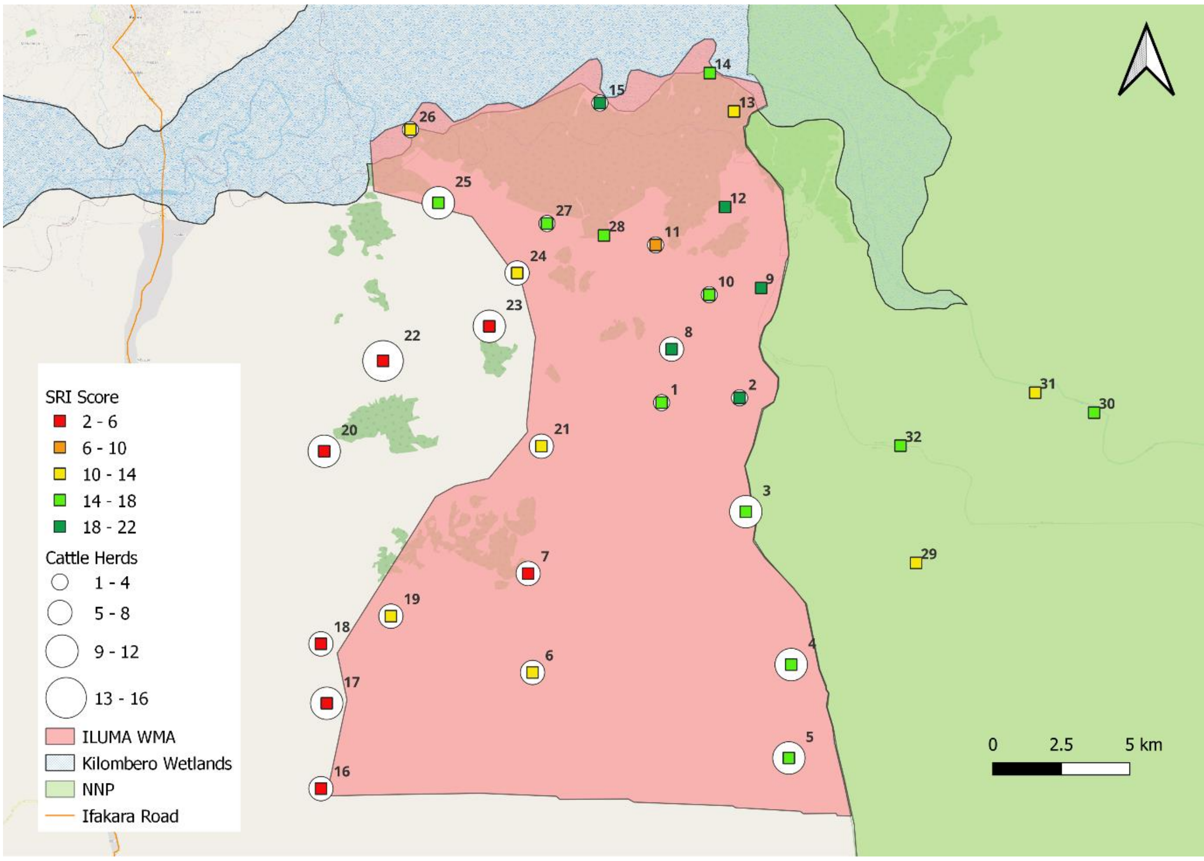

Figure 44. Map of ILUMA WMA showing each camp's SRI score represented from lowest (red) to highest (green), layered with combined (small and large herds) average values for cattle herding per camp.

3.7.2. Simpson's Index of Diversity.

In single explanatory variable analysis, livestock herding, timber harvesting, human settlement, the presence of a well and both rice agriculture and the farming of other tillage crops were all associated with reduced values for SID. In multiple explanatory variable analysis however, livestock herding and fishing were the only two significant human activities. Both of these variables were associated with reduced SID, but the effect size for the former was more than twice the latter (see Table 7 for details and Figures 45 and 46 for visual representation).

Table 7. Results of single and multiple explanatory variable(s) generalized linear regression analyses of scaled human activity indicators as determinants of the estimated Simpson's Index of Diversity Index (SID) for each camp surveyed, with statistically significant associations highlighted in bold. The best fit models identified for this SID outcome assumed a Gamma distribution and log link function for the dependent variable.

	Single Independent Variable			Multiple Independent Variables		
Activity	β ± SEM	t	P	β ± SEM	t	P
Livestock Herding	**-0.2525 ± 0.0420**	**-6.01**	**<0.0001**	**-0.2183 ± 0.0513**	**-4.254**	**0.0002[a]**
Charcoal Burning	-0.1134 ± 0.0616	-1.842	0.0754	0.0306 ± 0.0363	0.842	0.4069[b]
Timber Harvesting	**-0.0889 ± 0.0433**	**-2.054**	**0.0488**	-0.0137 ± 0.0254	-0.540	0.5938[c]
Fishing	-0.0326 ± 0.0467	-0.697	0.4913	**-0.0823 ± 0.0295**	**-2.788**	**0.0094[a]**
Hunting	-0.0294 ± 0.0447	-0.659	0.5151	0.0044 ± 0.0245	0.180	0.8586[b]
Human Settlement	**-0.1911 ± 0.0577**	**-3.314**	**0.0024**	-0.0455 ± 0.0515	-0.883	0.3850[b]
Well	**-0.2445 ± 0.0740**	**-3.306**	**0.0025**	0.0522 ± 0.0703	0.742	0.4642[b]
Meat Poaching	-0.0390 ± 0.0437	-0.893	0.379	0.0012 ± 0.0252	0.047	0.9632[b]
Human Presence	-0.3654 ± 0.0889	-4.109	**0.0003**	-0.1289 ± 0.0742	-1.739	0.0931[a]
Rice Farming	**-0.1788 ± 0.0436**	**-4.100**	**0.0003**	0.0206 ± 0.0414	0.498	0.6225[b]
Other Tillage Farming	**-0.2183 ± 0.0430**	**-5.078**	**<0.0001**	-0.0203 ± 0.0512	-0.396	0.6950[b]

SEM: Standard error of the mean.

[a] As estimated from the final, most parsimonious best-fit GLM, in which this was included on the basis of either being a significant (P≤0.05) determinant of SID or approached significance (P≤0.10) as a determinant of SID and significantly (P≤0.05) improved the goodness of fit based on the estimated Akaike Information Criterion (AIC).
[b] As estimated from the last GLM in which this variable was still included before being removed on the basis that it was not a significant determinant of the SID (P>0.05) or approached significance (P≤0.10) but did not significantly improve the goodness of fit based on the estimated AIC (P>0.05).

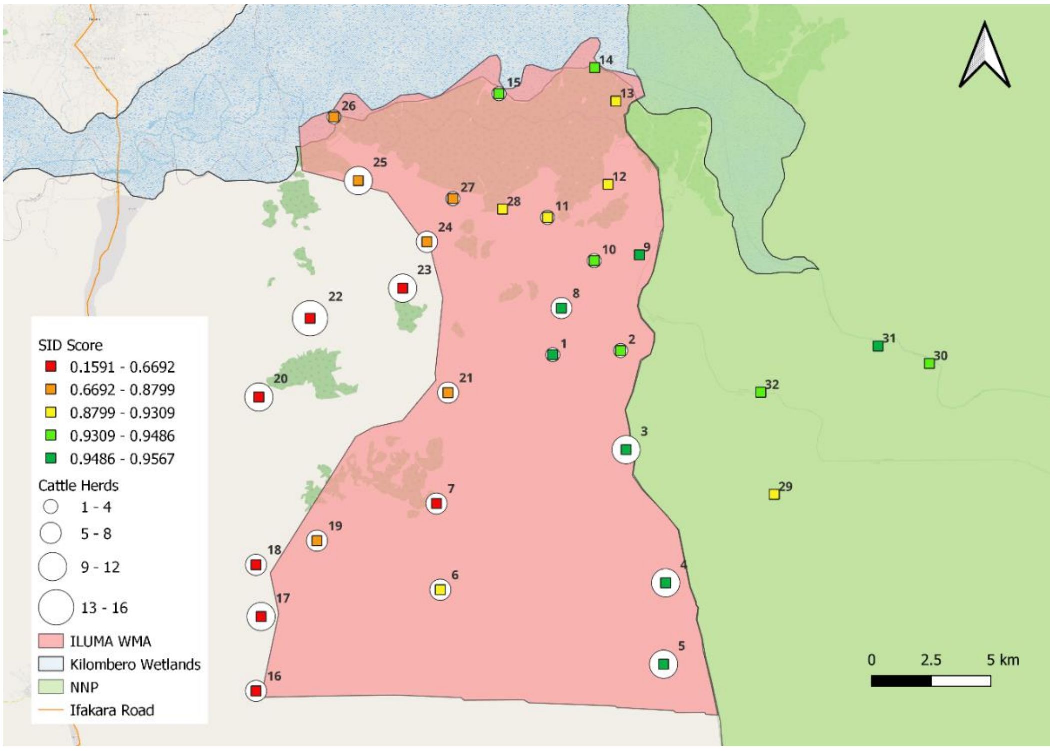

Figure 45. Map of ILUMA WMA showing each camp's SID score represented from lowest (red) to highest (green), layered with combined (small and large herds) average values for cattle herding per camp.

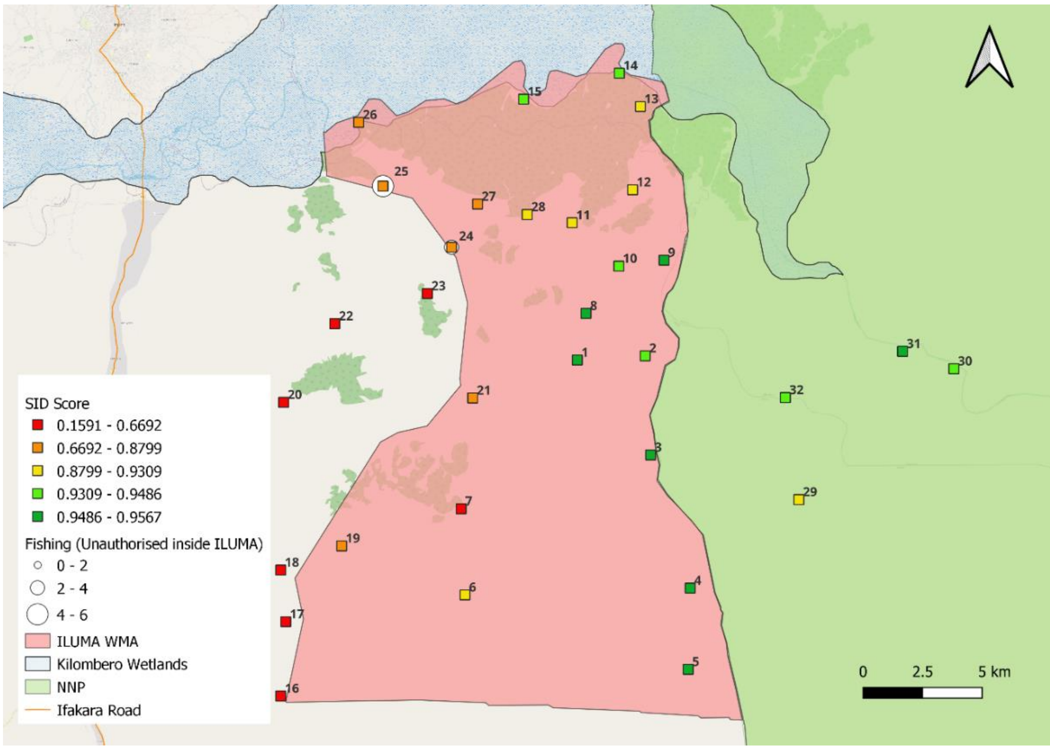

Figure 46. Map of ILUMA WMA showing each camp's SID score represented from lowest (red) to highest (green), layered with unauthorised (inside ILUMA WMA) fishing average values per camp.

3.7.3. Subjective Natural Ecosystem Integrity Index.

This index had the largest number of human activities significantly impacting its outcome in both single and multiple explanatory variable(s) analyses. Significant activities identified by initial single explanatory variable analyses were livestock herding, charcoal burning, human settlement, well, human presence, rice, and other tillage farming (see Table 8 for details), these activities all resulted in a lower SNEII score. Livestock herding, human settlement and both agriculture types had greater than twice the effect of charcoal burning. Livestock herding, charcoal burning, timber harvesting, human settlement and both rice and other tillage agriculture all proved significant multiple explanatory variable analysis (see Table 8 and Figures 47, 48, 49, 50, 51 and 52). Charcoal burning and timber harvesting led to an increased score in multiple explanatory variable analysis, it should be noted that the presence of these activities does not increase the score on the index but rather, these activities can only take place in areas where the ecosystem is largely intact and the raw materials required are available, hence they occur in ecologically intact areas.

Table 8. Results of single and multiple explanatory variable(s) linear regression analyses of scaled human activity indicators as determinants of the estimated Subjective Natural Ecosystem Integrity Index (SNEII) for each camp surveyed, with statistically significant associations highlighted in bold. The best fit models identified for this SNEII outcome assumed a Gaussian distribution and identity link function for the dependent variable.

	Single Independent Variable			Multiple Independent Variables		
Activity	β ± SD	t	P	B ± SEM	t	P
Livestock Herding	**-29.292 ± 3.082**	**-9.505**	**<<0.0001**	**-17.017 ± 2.910**	**-5.849**	**<<0.0001[a]**
Charcoal Burning	**-14.459 ± 5.579**	**-2.592**	**0.0146**	**6.828 ± 2.266**	**3.014**	**0.0058[a]**
Timber Harvesting	-7.654 ± 6.012	-1.273	0.213	**4.413 ± 1.959**	**2.253**	**0.0333[a]**
Fishing	1.085 ± 6.169	0.176	0.862	3.641 ± 2.423	1.503	0.1454[b]
Hunting	-4.898 ± 6.107	-0.802	0.429	-0.879 ± 2.191	-0.401	0.6917[b]

Human Settlement	**-23.250 ± 4.481**	**-5.188**	<<0.0001	**-6.527 ± 2.749**	**-2.375**	**0.0256[a]**
Well	**-21.436 ± 4.773**	**-4.491**	**0.0001**	3.315 ± 3.011	1.101	0.2814[b]
Meat Poaching	-8.222 ± 5.987	-1.373	0.18	-1.249 ± 2.004	-0.623	0.5388[b]
Human Presence	**-21.616 ± 4.746**	**-4.555**	**0.0001**	5.419 ± 3.183	1.702	0.1011[b]
Rice Farming	**-27.900 ± 3.486**	**-8.004**	<<0.0001	**-9.423 ± 2.901**	**-3.248**	**0.0033[a]**
Other Tillage Farming	**-29.434 ± 3.037**	**-9.693**	<<0.0001	**-9.668 ± 3.730**	**-2.592**	**0.0157[a]**

SD: Standard deviation of the coefficient point estimate.
P: P – Value.
[a] As estimated from the final, most parsimonious best-fit GLM, in which this was included on the basis of either being a significant ($P \leq 0.05$) determinant of SEII or approached significance ($P \leq 0.10$) as a determinant of SEII and significantly ($P \leq 0.05$) improved the goodness of fit based on the estimated Akaike Information Criterion (AIC).
[b] As estimated from the last GLM in which this variable was still included before being removed on the basis that it was not a significant determinant of the SEII ($P > 0.05$) or approached significance ($P \leq 0.10$) but did not significantly improve the goodness of fit based on the estimated AIC ($P > 0.05$).

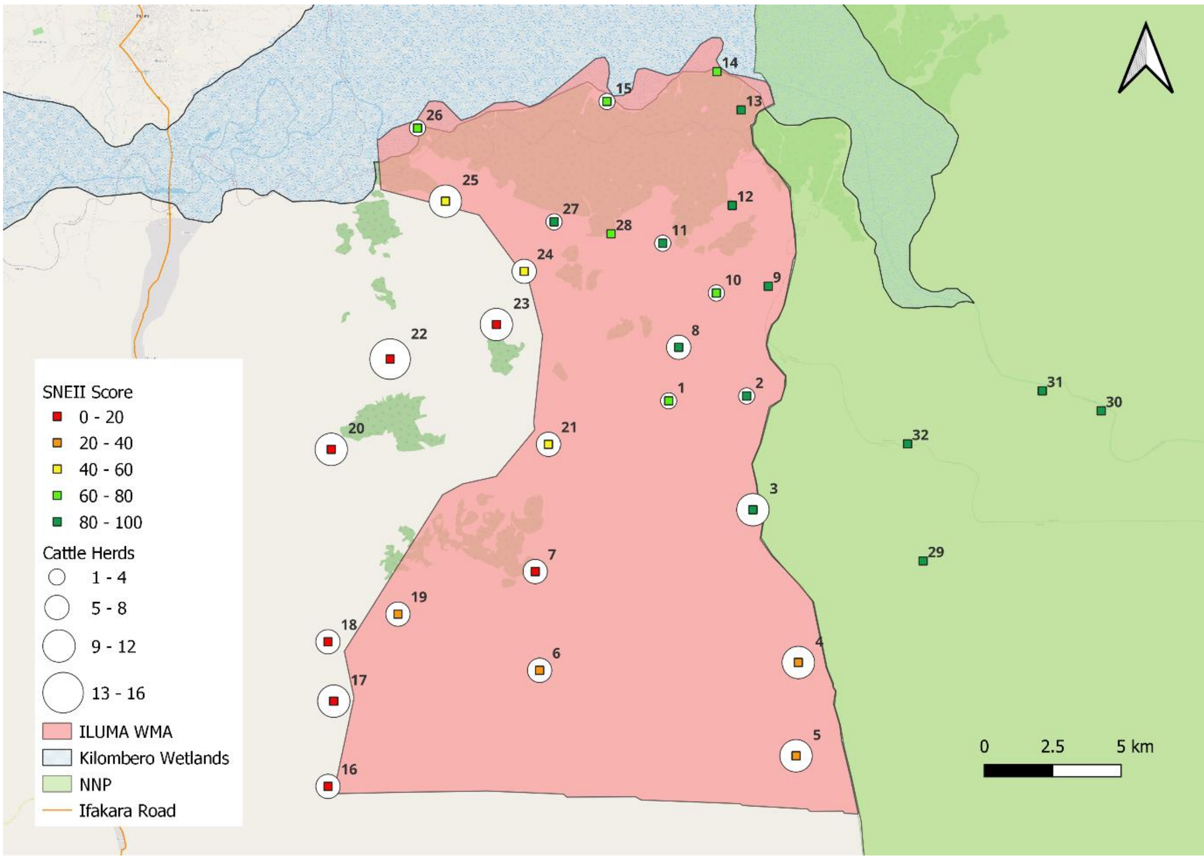

Figure 47. Map of ILUMA WMA showing each camp's SNEII score represented from lowest (red) to highest (green), layered with combined (small and large herds) average values for cattle herding per camp.

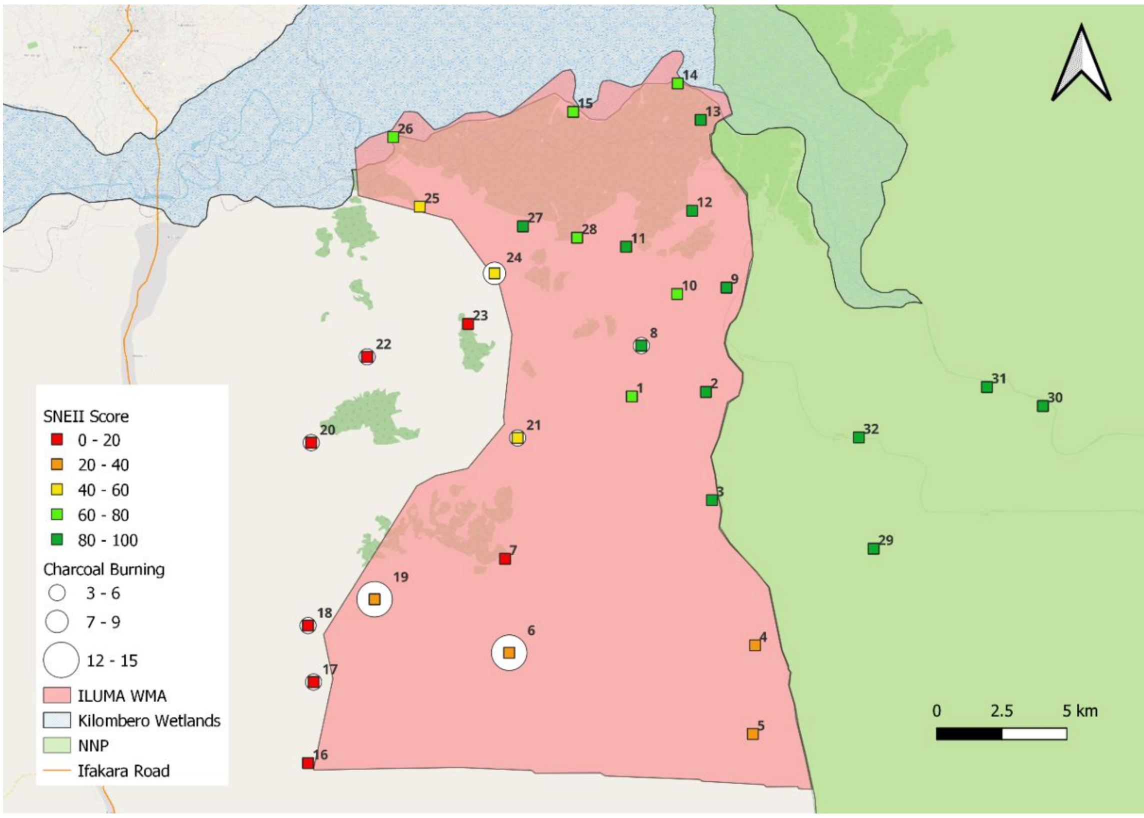

Figure 48. Map of ILUMA WMA showing each camp's SNEII score represented from lowest (red) to highest (green), layered with charcoal burning average values per camp.

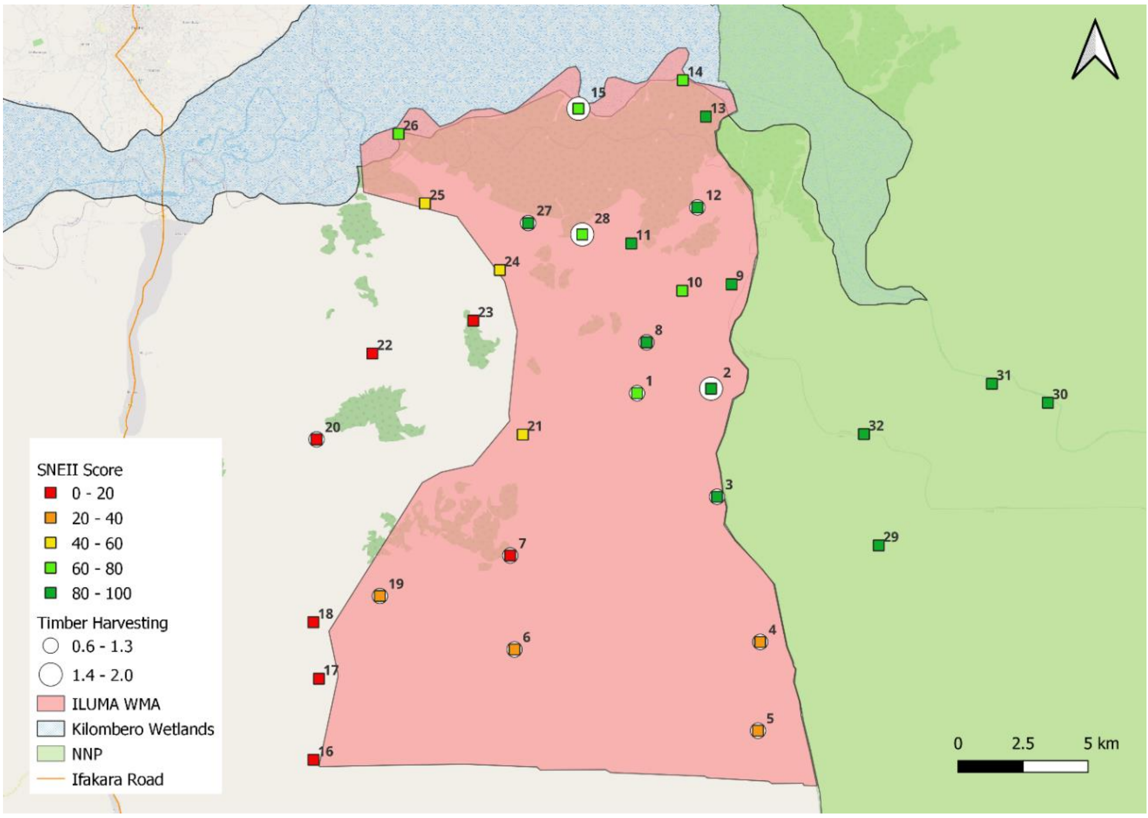

Figure 49. Map of ILUMA WMA showing each camp's SNEII score represented from lowest (red) to highest (green), layered with timber harvesting average values per camp.

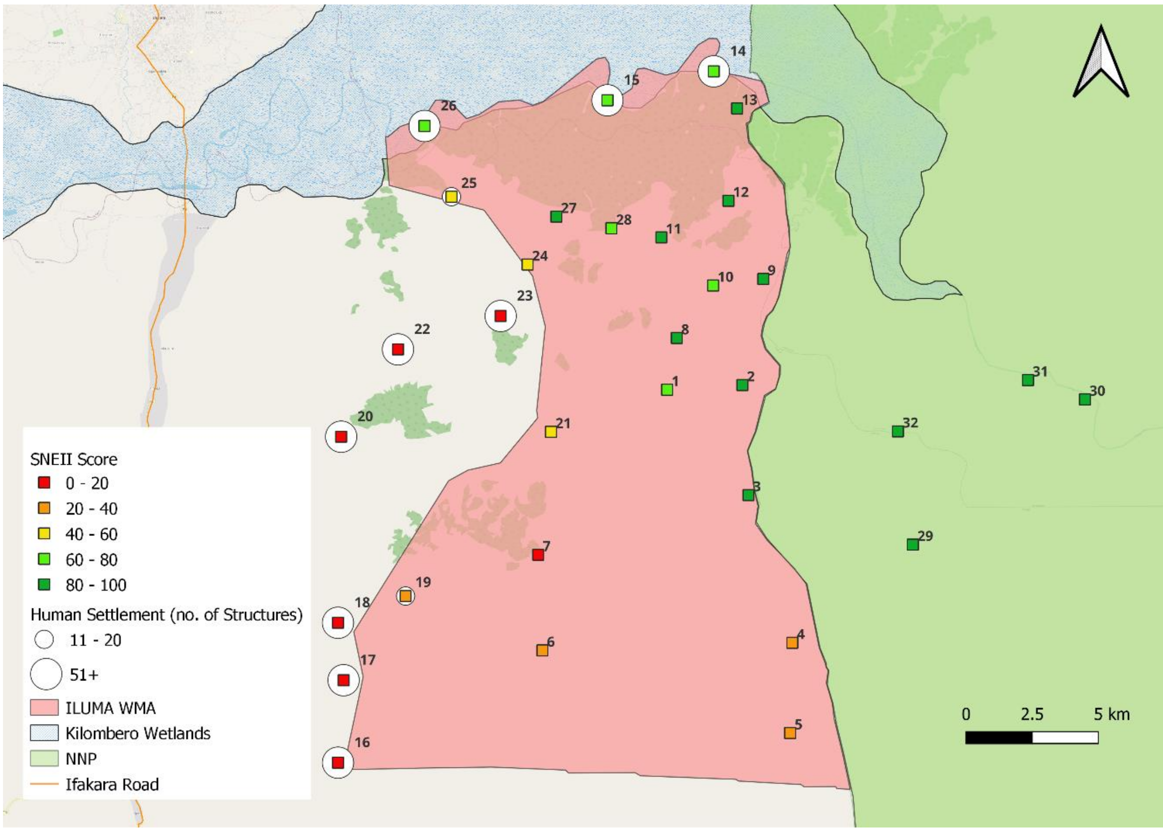

Figure 50. Map of ILUMA WMA showing each camp's SEII score represented from lowest (red) to highest (green), layered with human settlement average values per camp.

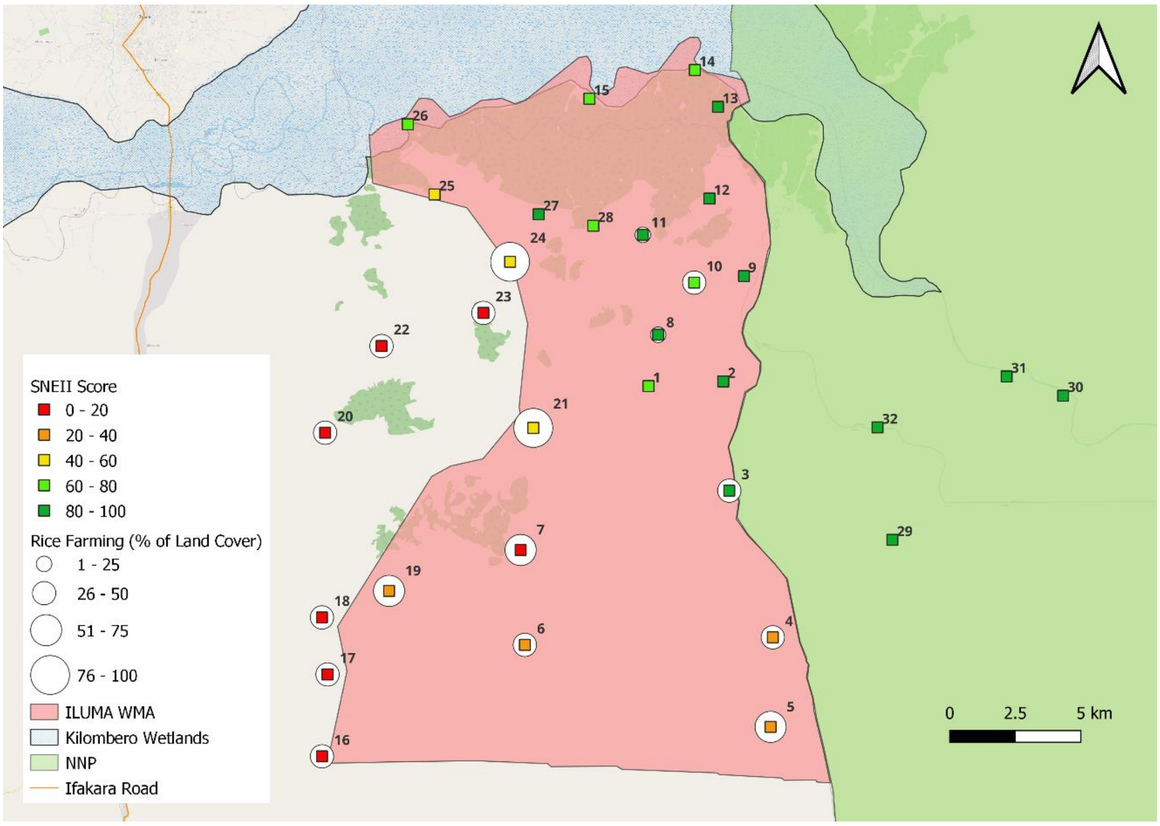

Figure 51. Map of ILUMA WMA showing each camp's SNEII score represented from lowest (red) to highest (green), layered with rice farming (% land cover) average values per camp.

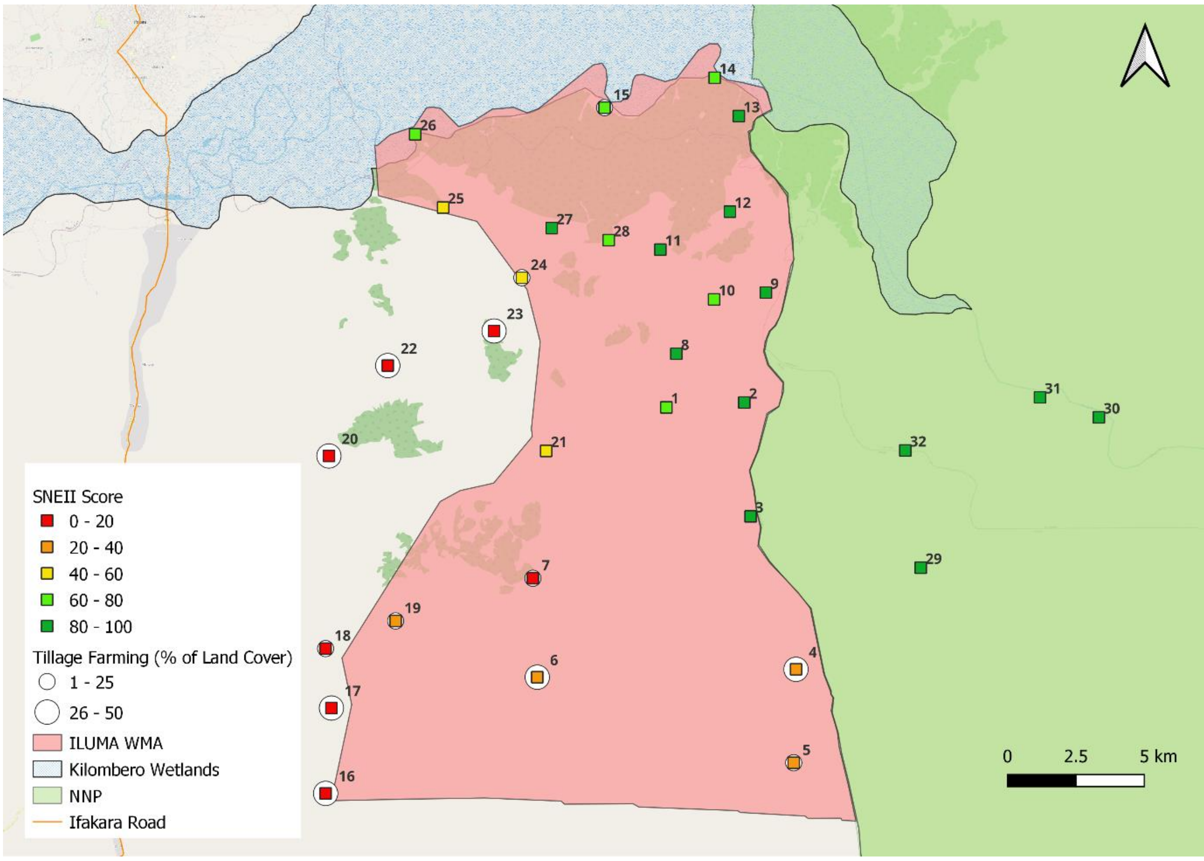

Figure 52. Map of ILUMA WMA showing each camp's SNEII score represented from lowest (red) to highest (green), layered with other tillage crops farming (% land cover) average values per camp.

3.7.4. Objective Natural Animal Community Integrity Index.

In single explanatory variable analysis of ONACII the following human activities were significant: livestock herding, human settlement, meat poaching, rice farming and other tillage agriculture. Of these however, only two namely livestock herding, and meat poaching remained significant in multiple explanatory variable analysis (see Table 9 for details and Figures 53 and 54 for visual representation). Both of these activities decreased ONACII score and had a similar magnitude of impact.

Table 9. Results of single and multiple explanatory variable(s) linear regression analyses of human activity indicators of scaled human activity indicators as determinants of the Objective Natural Animal Community Integrity Index (ONACII) for each camp surveyed, with statistically significant associations highlighted in bold. The best fit models identified for this ONACII outcome assumed a Gaussian distribution and identity link function for the dependent variable.

	Single Independent Variable			Multiple Independent Variables		
Activity	β ± SEM	t	P	β ± SEM	t	P
Livestock Herding	**-0.5132 ± 0.1574**	**-3.275**	**0.0027**	**-0.4419 ± 0.1514**	**-2.918**	**0.0067**[a]
Charcoal Burning	-0.3775 ± 0.1691	-2.233	0.1691	-0.1293 ± 0.1722	-0.751	0.4591[b]
Timber Harvesting	0.0363 ± 0.1825	0.199	0.844	0.1912 ± 0.1543	1.239	0.2255[b]
Fishing	0.2658 ± 0.176	1.51	0.141	0.1357 ± 0.1529	0.888	0.3822[b]
Hunting	-0.0618 ± 0.1822	-0.339	0.737	-0.4365 ± 0.1532	-0.029	0.9775[b]
Human Settlement	**-0.3741 ± 0.1693**	**-2.21**	**0.0349**	-0.1306 ± 0.1717	-0.761	0.4532[b]
Well	-0.3463 ± 0.1713	-2.022	0.0522	0.1040 ± 0.2311	0.450	0.6561[b]
Meat Poaching	**-0.4246 ± 0.1653**	**-2.568**	**0.0154**	**-0.3286 ± 0.1514**	**-2.170**	**0.0384**[a]
Human Presence	-0.2564 ± 0.1765	-1.453	0.157	0.2483 ± 0.2215	1.121	0.2718[b]
Rice Farming	**-0.5066 ± 0.1574**	**-3.218**	**0.0031**	-0.2547 ± 0.2063	-1.235	0.2272[b]
Other Tillage Farming	**-0.465 ± 0.1616**	**-2.877**	**0.0073**	-0.1706 ± 0.2223	-0.767	0.4494[b]

SD: Standard deviation of the coefficient point estimate.
P: P – Value.
[a] As estimated from the final, most parsimonious best-fit GLM, in which this was included on the basis of either being a significant (P≤0.05) determinant of SEII or approached significance (P≤0.10) as a determinant of ONACII and significantly (P≤0.05) improved the goodness of fit based on the estimated Akaike Information Criterion (AIC).
[b] As estimated from the last GLM in which this variable was still included before being removed on the basis that it was not a significant determinant of the NACI (P>0.05) or approached significance (P≤0.10) but did not significantly improve the goodness of fit based on the estimated AIC (P>0.05).

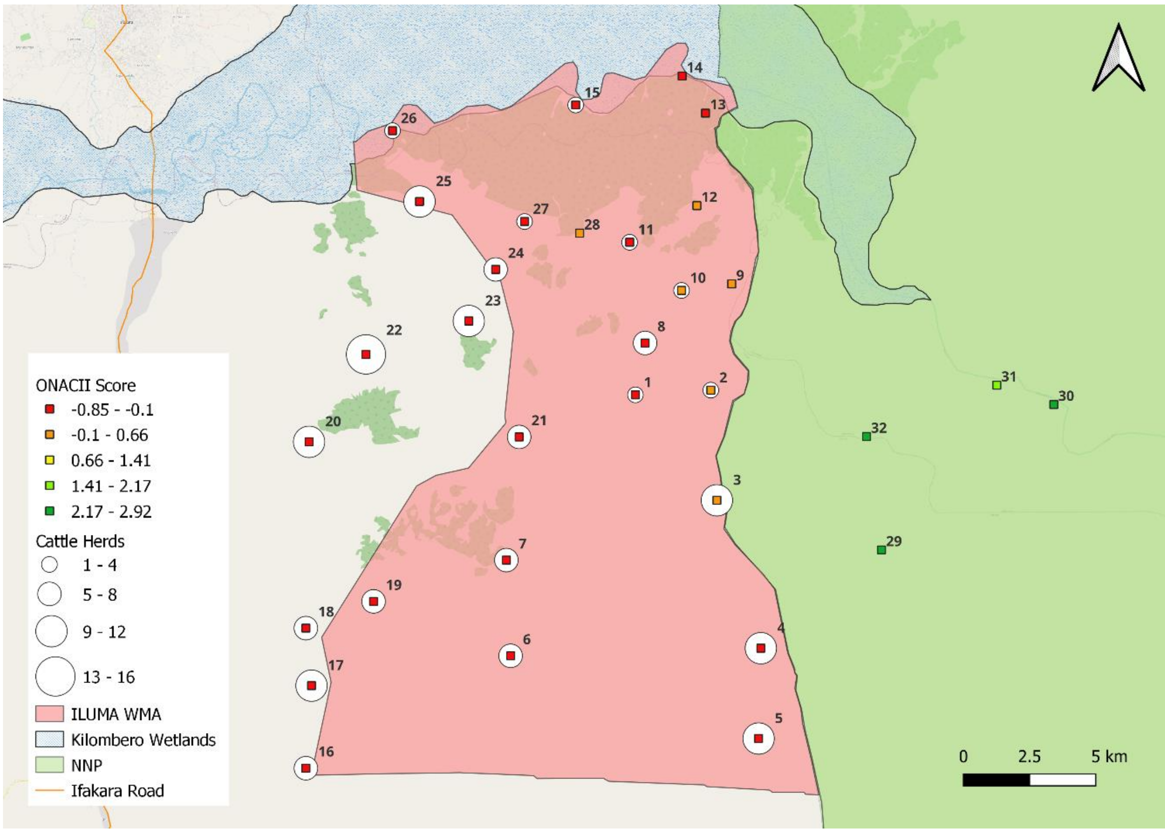

Figure 53. Map of ILUMA WMA showing each camp's ONACII score represented from lowest (red) to highest (green), layered with combined (small and large herds) average values for cattle herding per camp.

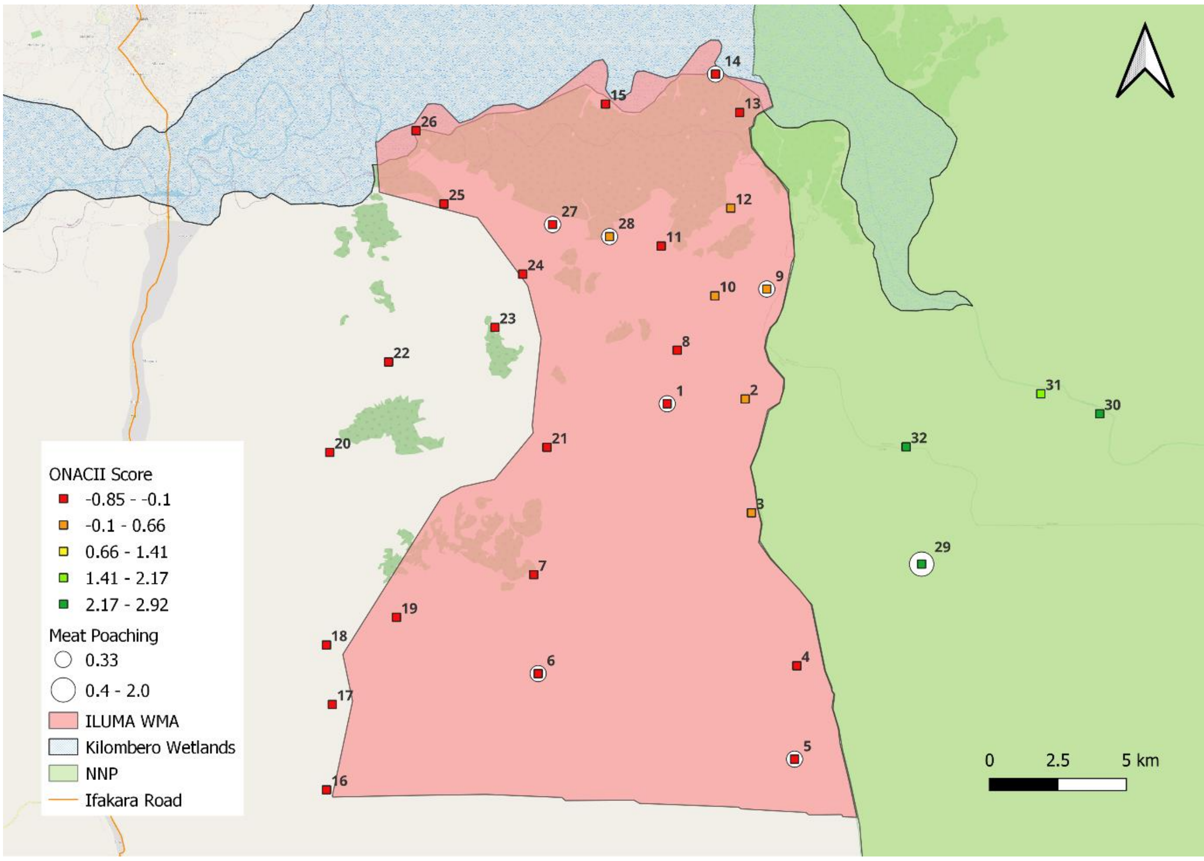

Figure 54. Map of ILUMA WMA showing each camp's ONACII score represented from lowest (red) to highest (green), layered with average values of meat poaching per camp.

Overall, one clear trend that is evident is that livestock herding has a significant negative impact on each index and is the single most quantitatively important variable in all four multiple explanatory variable models (see Tables 6, 7, 8 and 9). Furthermore, no other human activity consistently impacts upon all of these indices.

SNEII was the most sensitive to human activities as it was significantly associated with over half of the activities evaluated in the final multiple explanatory variables model. It was also the only index which confirms that the unauthorised presence of humans for an extended period of time, on a residential basis and the clearing of land for settlement and agriculture has a significant impact.

4. Discussion.

Data detected, gathered, and analysed throughout the course of this study indicate that there was both adherence to, and at times strong deviation from, the land use plans that had been negotiated and agreed with the stakeholder communities for ILUMA WMA.

4.1. De facto land use practices inside ILUMA WMA.

Over 600 detections of unauthorised community presence were recorded inside ILUMA's boundaries during the course of this study, with a clear gradient in the number and types of human activities seen across the survey area (see Figures 18 and 19). Unauthorised human activities were recorded most frequently close to the western and southern boundaries of ILUMA, where the WMA is bordered by formally established villages. As a general trend, the southwest experienced the highest levels of unauthorised human activity, which lessened in frequency approaching the northeast of the WMA and the eastern boundary with NNP (see Figure 36). Human settlement in particular followed this trend (see Figure 29).

Unauthorised human settlement marks a clear breech of the agreed land use plans, and the extractive and ancillary activities that are associated with human settlement such as land clearing or deforestation for building materials and agriculture, all alter the landscape and ecosystem functioning. Unauthorised human settlements within ILUMA's boundaries were clearly associated with high levels of land clearing and extractive activities. On the African continent, the area south of the equator accounts for 13% of the land globally that is facing degradation due to conversion of natural lands for agriculture or encroachment into protected areas, a phenomenon which is increasing in both extent and severity across the earth (Bai *et al.*, 2008). This degradation of natural ecosystems on a global scale is a crucial factor in why it is imperative for small-scale community-based conservation programmes, such as the one in place here, to be well maintained and in doing so could prove vital in preventing land degradation. The entire ecosystem is impacted upon by land clearing and degradation. Directly impacted are soils, vegetation and both surface and ground water resources, with a cascading effect on wild animal populations (Assessment, 2005). The structure of soil can be changed, nutrients lost, and soil erosion exacerbated by the conversion of natural forested land for agricultural purposes (Lake Victoria Basin Commission, 2007). Given these implications of unauthorised land clearing, it is evident that non-adherence to the land use plan may have severe consequences for ILUMA's ecosystem in the coming years. The potential of ILUMA to sequester carbon may also be negatively affected by this land degradation, given its land cover is predominantly miombo woodland - an ecosystem type with high carbon sequestration potential. Regrowing miombo wood sequesters 0.5 to 0.9 tons of carbon ha^{-1}per year, while soils in a regrowing miombo woodland sequester >100 tons of carbon ha^{-1}per year (Williams *et al.*, 2008). To put this into perspective, grassland soils in east Africa have a carbon sequestration potential of 0.3 to 1.9 tons of carbon ha^{-1}per year (Tessema *et al.*, 2020), far less than that of a miombo woodland system and drylands sequester just 0.05 to 0.7 tons of carbon ha^{-1}per year (Jindal, Swallow and Kerr, 2008). Rainforests have a much higher wood carbon sequestration potential with a 2021 study reporting that intact tropical mountain forests on the African continent store 150 tons of carbon ha^{-1}per year (Cuni-Sanchez *et al.*, 2021).

As documented in this study, while the establishment of human settlements usually had small areas of land cleared in their immediate surroundings to make way for various other crops, rice farming took place on a much larger scale throughout ILUMA (see Figure 30). Only very rarely were large areas found to be covered in tillage crops other than rice (see Figure 31). Rice agriculture is primarily a cash crop in the Kilombero valley, grown largely for sale rather than subsistence (Nkuba *et al.*, 2016), so it is correspondingly grown wherever suitable soil allows. The practice of rice farming in the Kilombero has long been established due to the largely flat topography of this low lying valley that seasonally floods and fertile *fluvisol* soil type that can retain water for long periods (Massawe, 2015). To achieve high rice yields, large amounts of freshwater are required to saturate the soils (Cao *et al.*, 2021). Rice farming practices in the Kilombero valley are largely dependent on direct rainfall, although artificial irrigation with water diverted via canals from streams and rivers is possible in some places (Alavaisha *et al.*, 2022). While the clearing of land was not observed frequently in rice cultivation in ILUMA WMA, the degradation of wetlands and ephemeral lakes certainly was. Clearing of land was not frequently seen in association with rice cultivation in ILUMA due to the locations that favour rice growth, such as valleys and areas that are low-lying and seasonally flood, which naturally have less tree cover and tend to be open and generally contain sparse vegetation, this permits rice growth with minimal land clearing. These areas also contained clay soils, much better suited to rice cultivation than the sandier soils observed in the elevated areas of ILUMA. Due to the nature and practice of rice paddy growth, and the large amount of water it requires, in many areas where rice farming was recorded in ILUMA degradation of a waterbody nearby was evident. One study site, camp 21, was even named after this: *Bwawa la Mpunga* which translates literally as "waterhole of rice". The majority of rice cultivation in ILUMA involved some level of water course diversion for irrigation, whether from ephemeral waterholes in the dry season or streams. The diversion of water from its original path caused waterholes to dry out quicker and provided less resources for the wildlife that depend on them. In some cases, water is dammed rather than diverted or drained and this keeps some locations wetter for longer into the dry season. In either case, the cultivation of rice in ILUMA, although not linked to large levels of deforestation, changes the movement of water throughout the ecosystem and alters water levels throughout the year. A study on the Kilombero wetlands, part of which is included in this study area, found that the flow of many rivers has been reduced and that a number of swamp areas have been reduced in size or dried up completely as a result of poor agricultural practices and deforestation in the Kilombero wetlands (Mombo *et al.*, 2011).

The most frequently detected unauthorised human activity in ILUMA was undoubtedly livestock herding. Over 1400 observations of cattle herds were made during the course of the study (see Figure 22). Detections were highest in the degraded camps of ILUMA, followed by the areas outside where herding is not restricted, but has to compete with agriculture as a land use option. Although it is clear in the land use agreement (District Authorities, 2016) that cattle grazing is not a permitted activity inside of ILUMA's boundaries, evidence reported here highlights that this agreement has been breached. The pressure on the land surrounding ILUMA WMA for cattle herding has been alleviated by unauthorised cattle herding within the WMA, the frequency of detections and their widespread encroachment especially in the western and southern areas of the WMA display just how widespread this human activity is inside the conservation area. If the clear boundaries of the WMA that border areas of human habitation are not monitored with some degree of frequency, then a situation such as the one portrayed currently in ILUMA takes place, whereby unmonitored boundaries allow cattle herding to encroach at an uncontrolled rate, at times deep into the WMA, and deteriorate land at the edges (and sometimes much deeper) of the conservation area, degrading the ecological integrity of the natural ecosystem.

ILUMA's habitat type is predominantly miombo woodland of different densities, and cattle herding in miombo woodland in Tanzania in an area with similar abiotic and biotic characteristics to this study revealed mixed ecosystem responses to cattle grazing (Mtimbanjayo and Sangeda, 2018). High intensity cattle grazing caused a significant negative effect on both the density and diversity of miombo tree species, while less intense herding, especially during the dry season, was shown to have no adverse effect on the ecosystem (Mtimbanjayo and Sangeda, 2018). Given the somewhat flexible nature of land use agreements for WMAs in Tanzania, carefully monitored and strictly enforced seasonal grazing is permitted in some WMAs, such as Enduimet WMA in northern Tanzania, for example. In these northern WMAs and more arid landscapes, mobile livestock grazing is the main livelihood (University of Copenhagen Department of Food and Resource Economics, 2015).

As evident from data collected during this study, the pressure on land inside and immediately outside ILUMA for livestock grazing is high, so perhaps rigorously regulated seasonal grazing in ILUMA may help to control the level of unregulated herding, by permitting it at certain times and in certain areas only, and in doing so protecting the areas that are highly valuable for wildlife. An excellent example of where livestock herding and wildlife populations can coexist is seen in the South Rift, Kenya. A study on the coexistence between livestock and wildlife in a heterogenous landscape found that a diverse and bountiful wildlife population was maintained when land was shared with livestock (Tyrrell, Russell and Western, 2017). Careful prior planning was required before its implementation as the grazing plan implemented depends upon spatial and temporal separation between cattle and wildlife. By permitting cattle to graze inside the conservation area only during the dry season, and only in particular locations, it ensured that diverse resources remain in place for wildlife. The difference between the aforementioned study (through rangelands) and the study area examined during this data collection (a WMA bordering a national park), combined with the contrasting habitat types, suggests that wet season grazing may be a more suitable approach for ILUMA WMA. The village lands outside ILUMA WMA are used for the production of agricultural crops during the wet season, displacing cattle and adding more pressure to land, by permitting wet season grazing inside the WMA, land use pressure may be alleviated. Cattle grazing inside the WMA during the wet season can enhance productivity by preventing the overgrowth of perennial grasses and encouraging shorter more-nutritious grasses to grow (Fynn *et al.*, 2016) which can benefit both livestock and wildlife. Data collected during this study suggests that animals from NNP move through ILUMA and use it seasonally, in the wet season especially many wildlife species travel into NNP, the grazing of cattle within the WMA during this season would lead to less competition over resources. The dry season is also an ideal time for tourism, an enterprise that would not overlap well with cattle grazing. From the data collected and presented here, it is evident that current rates of livestock encroachment into the WMA is unsustainable and without an intervention such as a wet season grazing plan, encroachment by cattle herds may continue to degrade the ecological integrity of ILUMA WMA.

The frequency of detection of the majority of unauthorised human activities in ILUMA WMA was quite low when compared to livestock herding and human settlement. The exception to this rule, however, is charcoal production, which was observed 290 times over the course of the study (see Figure

23). Within the land use plan of ILUMA WMA, some charcoal burning is permitted, but this requires a permit to be obtained through well-defined procedures. All of the charcoal burning activities recorded in this study were unauthorised. Charcoal burning was detected most often in camps 6 *(Bwawa la Namamaba*) and 19 (*Bwawa la Selasussi*), followed by camps 8 (*Bwawa la Njuju*) and 24 (*Bwawa la Mkwajuni).* The majority of ILUMA's land cover is miombo woodland, a land cover type which is prized for extractive purposes for wood products, including construction materials and charcoal (Abbot and Homewood, 1999). A leading cause of biomass loss in miombo woodlands is charcoal production (Chidumayo, 1991), and in the forests of Mozambique, charcoal production was identified as the main cause of degradation (Sedano *et al.*, 2016). The highest rate of deforestation and forest degradation on the African continent during the early 21st century occurred in Tanzania (FAO, 2010), with this being a significant problem even in protected forest areas (Bracebridge *et al.*, 2005). However, it is well documented that miombo woodlands have a large and rapid capacity for regeneration (Boaler and Sciwale, 1966, Schwartz and Caro, 2003). Therefore, future efforts to prevent activities that degrade these woodlands, such as charcoal production and land clearing for settlement and agriculture, could see ILUMA's miombo woodlands regenerate quite quickly.

In contrast to the aforementioned clear violations of ILUMA WMA's land use plan, one section of the management plan that is being adhered to well is the authorised fishing camps in the north of ILUMA, along the banks of the Kilombero river, namely camps 14 (*Mikeregembe*), 15 (*Mdalangwila*) and 26 (*Funga*). Very few detections of unauthorised activities were observed at these camps, and the areas immediately outside of these settlements appeared ecologically intact with very little evidence of degradation (See figures 39 and 41). The residents of these locations have permission to extract fish from the Kilombero river and sell it as a livelihood. Fishing is carried out with nets, in dug-out canoes hollowed from tree trunks and is traditional in its practice. The settlements are much smaller in size than the formally established villages outside of ILUMA, and no large-scale agriculture was recorded in the vicinity of these camps. The growth of vegetables, such as spinach and aubergines was detected, but the plots they were cultivated in were directly adjacent to the individual settlements, never exceeded $5m^2$ in area and were used only for personal consumption by the household. From observations made and data recorded, as well as conversations with the VGS, the residents of these settlements were, generally speaking, strictly abiding by the land use plan and maintained all human settlement in a confined area. All three of the camps displayed intact, dense groundwater forest just a few hundred meters from the centre of the settlements.

The presence of authorised residents may actually be helpful in deterring unlawful activity in the areas surrounding these settlements. Due to the mutually beneficial nature of the fishing camps for both the residents, who practice sustainable livelihoods provided by the intact natural ecosystem that surrounds them, residents are quick to report suspicions of illegal activities within the WMA to the VGS. This evidence clearly demonstrates that well-managed human settlements within a protected area can, not only have a neutral effect on the ecological intactness of an ecosystem, but actually bolster its integrity through community vigilance and reporting. This illustrates how sustainable livelihoods for local people and high ecological integrity may be achieved concurrently if the formally agreed land use plans are adhered to. Solutions like this could perhaps be beneficial to other CBC areas, but adequate planning must be in place prior to authorisation of extraction to ensure that stocks of natural resources (of fish in this case, but the same should apply in principle to timber harvesting or cattle grazing) are robust enough to withstand controlled extraction. The northern portion of ILUMA WMA has the advantage of having the Kilombero river flowing through it, which can support livelihoods through a single resource extraction activity with minimal impact upon the terrestrial ecosystem, which may not be the case in other CBC areas.

It is evident from the data collected and analysed throughout this study that there is a distinct contrast between the majority of the community defined land use plans and the de facto land use practices in ILUMA WMA. The impact of these *de facto* practices is now discussed on the overall wild mammal population.

4.2. The impact of de facto land use practices on wildlife populations in ILUMA WMA.

A clear prevailing trend in wild herbivore detections was observed over the course of this study. Peak detections occurred either in the *pristine* camps of ILUMA or in NNP, with a reduction in detections evident in the *degraded* areas of ILUMA (see Figures 14 and 15). The lowest frequencies of detections of wildlife were always in the fully domesticated areas. The gradient of wildlife detections increases as the conservation status of the land increases, displaying that ILUMA WMA is acting as an important buffer zone for NNP by providing a protected area with extensive woodland, forest and floodplain habitats that are useful for many species outside of the national park. It has already been demonstrated that mammal diversity increases when miombo woodland is interspersed with other habitat types such as savannas and riverine areas (Campbell, 1996) and it was notable that during this study higher biodiversity was observed in the woodlands of ILUMA WMA than in the drier acacia savanna nearby inside NNP (see Table 5 and Figures 37 and 38). This rich diversity within ILUMA WMA is due (at least in part) to portfolio effects (Schindler, Armstrong and Reed, 2015). The environmental heterogeneity in ILUMA allows the animal community to have resistance to environmental change by providing a mosaic of habitats that permit resource exploitation year – round that are less sensitive to change than single ecosystem types and provides opportunities for dispersion amongst different habitat types if conditions were to become unfavourable. The pristine areas of ILUMA therefore offer an ideal environment to support a large diversity of wild mammals, and further emphasises the need for human encroachment into the WMA to be regulated as it is providing a vital service to wildlife.

A similar example of where a WMA is benefiting populations of large mammals adjacent to national parks, is Burunge WMA adjacent to Tarangire NP in northern Tanzania (Kiffner *et al.*, 2020b). According to this study, although elephants occasionally reached greater densities inside Tarangire NP than in Burunge WMA, species specific density estimates for nine other mammals: giraffe, zebra, wildebeest, Kirk's dik-dik, buffalo, waterbuck, warthog, impala and vervet monkey, were not significantly different between the two areas. It was also reported that the populations of elephant, impala and wildebeest increased significantly over the course of the study in Burunge WMA, illustrating just how effectively financially viable, community-managed WMAs can support wild mammal densities communities comparable to those of rigorously protected national parks. It should be noted that management of the WMA was significantly strengthened over the course of the study in Burunge WMA, and the authors believe this to have been a contributing factor to wild mammal population growth. Burunge WMA was established in 2006, 9 years prior to ILUMA, it is also smaller in size, 280km^2. Based on the trends in wild mammal data recorded in this study, one can be optimistic that a situation similar to Burunge WMA could be achieved in ILUMA WMA, given sustainable business models, enhanced management and ongoing monitoring and enforcement of unauthorised activities.

The top three herbivore species detected in this study were elephant, hartebeest, and buffalo (see Figures 14 and 15). Prior research indicates that over three quarters of the biomass of an untransformed miombo woodland site is expected to be comprised of elephant, buffalo and zebra (Campbell, 1996), the animal activity surveys from the pristine parts of ILUMA WMA aligns reasonably well with expected composition. A difference is noted between the expected zebra population for a miombo woodland and the observed zebra population in ILUMA WMA. This difference also contrasts with a study on a miombo woodland ecosystem in Malawi, which found the recordings of zebra to far outweigh those of hartebeest (598 detections vs 160 detections) (Reece *et al.*, 2021), however composition of this area did vary from expected miombo woodland biomass, as it was found that elephants were under represented. This demonstrates how different specific natural pressures and human disturbances in each miombo woodland site can influence the population dynamics of large wild herbivores in different ways. Hartebeest live in the boundaries between glades or parkland and woodland or scrub (Kingdon, 2015), meaning that the microheterogeneities in habitat type in ILUMA WMA and on its border with NNP offer ideal habitat. Hartebeest undertake very small-scale seasonal migrations, and move seasonally along drainage lines, of which there are plenty in miombo woodland, moving down the drainage line in search of water and fresh grass in the dry season and up the drainage line in the wet season to better drained soils. ILUMA acts as a dry season refuge for this species by providing it with short nutritious grasses and a source of surface water. Hartebeest are also more likely to enter open woodland than other antelope and are associated with the edge of that ecosystem and more open glades (Estes, 2012), the females take this route more often than males, frequently searching for fresh grass. Males conversely exploit many vegetation types and disperse along the margins of drainage lines where they mark their territories (Kingdon, 2015).

One of the least frequently detected animals throughout the course of this study was puku, with just seven detections made (see Figures 14 and 15). Regrettably, this is representative of the state of the puku population in the Kilombero valley currently. During the 1990's the Kilombero valley hosted a puku population of approximately 70,000 individuals, which represented 75% of the entire global population for this species (Jenkins, Maliti and Corti, 2003). The Kilombero valley stands as one of the two remaining areas where puku still survive in Tanzania, and it is a species that is considered near threatened (Kiffner *et al.*, 2020b). The high influx of human settlement and floodplain agriculture in the valley since the early 1990's, combined with associated meat poaching, has had a detrimental impact on the Kilombero valley puku population, the current size of which has recently been estimated between 1000 to 2000 animals (Daconto *et al.*, 2018). In the 1980's, the large increase in cattle densities across the Kilombero valley was identified as threat to the puku population (Corti *et al.*, 2002). In the early 2000's it was revealed puku were concentrated in the central floodplain due to displacement on the periphery by cattle, and that the habitats used by cattle were avoided by puku (Corti *et al.*, 2002, Bonnington, Weaver and Fanning, 2007). ILUMA WMA can play a vital role in rebuilding this population as it includes prime puku habitat and currently hosts a small population (Daconto *et al.*, 2018). Due to year-round breeding and a short inter-calving period (Estes, 2012), puku populations can grow rapidly when allowed to, so they should be able to recover quickly in ILUMA if the WMA can ensure *de facto* patterns of land use practices that are consistent with its established land use plan.

The herbivore with the most obviously heterogeneous distribution pattern of detections in this study was impala (see Figures 14 and 15). Impala were recorded at only three locations inside ILUMA, and then only at very low frequencies, but were by far the most detected species inside NNP. This stark contrast in detection frequency is most likely due to the ecology of the species, which prefers the edge areas between grasslands and denser woodlands in acacia areas (Kingdon, 2015). NNP contains far more acacia savanna habitat than ILUMA WMA. Shade, moisture and high quality grazing or browsing are required for the species, which are highly residential and generally stay within a 10km range (Kingdon, 2015). The impala can alternate from being a grazer in light woodlands and low height grassland when grasses are lush during the wet season, to a browser in areas where foliage and shoots are available during the dry season (Estes, 2012). Impala are known to form larger groups during the wet season and splinter into smaller factions when grazing material becomes less abundant (Mramba, 2022). Female impalas form large clans and this may explain why such large numbers of impalas were found in NNP (Kingdon, 2015).

Sable and greater kudu were the two antelope species detected more often during transect surveys as opposed to radial surveys, while hartebeest were detected with similar frequencies in both types of survey (see Figures 14 and 15). The link between these three species being detected either equally well (hartebeest) or significantly better (sable and greater kudu) in transect surveys probably lies in their behavioural ecology. All three species either prefer to occupy ecotones or require more than one habitat type throughout the year. As discussed in the previous section, hartebeest, move up and down drainage lines to consume the best available vegetation during the course of a year. While hartebeest remain in the ecotone, sable are an antelope species that favour a mosaic of grassland and woodland habitats and are closely associated with well-watered, open miombo woodlands, that support understory grasses. Miombo woodlands are exploited when understory grass is readily available, sable also range through open grasslands and small floodplains seeking high quality grasses, with males leaving territorial markings along trails (Estes, 2012). A study following three herds of sable found that their seasonal range covers approximately half of their annual range and that the three herds although differing in the amount of time spent, made use of almost all vegetation types in the study area (Hensman *et al.*, 2014). A 2012 study conducted on the dependency on water in sable, found that compared to zebra, sable travel 25% greater distances to water due to the location of their home range during the dry season. It is the ability of this antelope to survive for longer periods between drinking water, that permits them to occupy regions that are less heavily exploited by grazers, and travel longer distances during the dry season (Cain III, Owen-Smith and Macandza, 2012). These noticeable patterns in sable ecology correlate well with the patterns of detections made throughout this study.

Greater kudu undertake greater seasonal movements than other *Tragelaphini,* and, similar to sable, greater kudu utilise woodland during the wet season and move to find the most nutrient-rich vegetation during the dry season and aim to avoid tough perennial grasses (Estes, 2012). The size of home ranges for the greater kudu are highly variable and depend on habitat type and the distribution patterns of resources within them (Allen-Rowlandson, 1980). All three of these species employ similar, albeit slightly different, survival strategies and it is the commonalities between them that causes them to be detected with similar or greater frequency in transect surveys as compared with radial surveys. Their home ranges are all typically larger than most of the other wild herbivores in this study area. Consequently, it seems likely that these species more often crossed the same paths that the field team travelled when conducting transect segment surveys, whereas generally smaller species, with smaller home ranges that were detected more frequently in the areas immediately surrounding waterbodies.

Wild carnivore detections during these surveys were less frequent than wild herbivore detections (see Figures 16 and 17). This is to be expected as carnivores occupy a higher trophic level than herbivores. In general, this study detected wild carnivores infrequently, with some exceptions. Water mongoose was the most frequently detected small carnivore. It should be noted that this species has very distinctive tracks and behaviours that leave behind evidence of their presence, (Baker, 1989), such as gathering shellfish and crabs from waterholes and rivers and discarding clusters of broken shells around wooden "anvils" used to smash them open as was often observed all across ILUMA (see Figure 10). The largest carnivore included in this study, lion, was detected just 15 times over the entire course of data collection. Lions and hyenas occupy the same ecological niche, with up to 95% of hyenas range being shared by lion across the continent (Périquet, Fritz and Revilla, 2015), the home ranges of lions can vary widely from between 20 to 400 km^2 , depending on prey numbers available (Estes, 2012), males travel longer distances than females with data collected from Hwange National Park revealing that female lions home ranges average 388km^2, while is the corresponding figure for males 478km^2 (Grigione *et al.*, 2002), these figures however are on the more extreme end of their range. Female hyenas, like lions, travel smaller distances than males, as they centre around their dens and the average home territory of hyenas is 30km ^{2}, this however can be much larger in areas where prey are scarce (Kingdon, 2015). The large home range of lions may provide an example as to why it was detected far less than hyenas throughout the course of the study, as they travel large distances, which may not have regularly overlapped with the field team.

Hyena was second only to African wild cat as the most frequently detected large carnivore species during this study (see Figures16 and 17). It is expected that in miombo woodland, this species comprises the majority of the predator biomass (Fritz *et al.*, 2011). A study carried out in Kasungu National Park, Malawi, found that a significant predictor for detection of hyena is the detection of prey, and concluded that allowing for this direct causal effect, neither habitat type nor distance to the boundary of a protected area had any bearing on the detection of hyena (Davis *et al.*, 2021). Given the above factors with ILUMA WMA providing a plethora of prey opportunities, mixed habitat stabilising herbivore populations through portfolio effects, and boundaries to both human settlement and a national park, in combination with hyena comprising the majority of predator biomass in miombo woodlands, it is unsurprising that this species was detected as often as reported here.

Uniquely, hyenas were the only carnivore species that were detected more often during transect surveys than radial surveys around waterbodies (Contrast Figures 16L and 17I). A causal factor in this may be the large range size of hyena, in conjunction with the use of tracks and paths by large-ranging carnivores, a 2021 review on mammal use of roads found the order *Carnivora* had the most species using roads and/or paths (Hill, DeVault and Belant, 2021). Another study that should be highlighted to clarify this point, reported that poorly formed roads, essentially tracks similar to many of the paths followed on transect surveys in ILUMA WMA, established signs of concentrated predator activity relative to otherwise comparable off-path areas. Although the target species in that study differs from the current one, predator activity was reported on roads and/or paths between 12 and 261 times more than off-road/path sites (Raiter *et al.*, 2018). Hyenas average territories are 30km^2 in size (Kolowski and Holekamp, 2008, Estes, 2012), but the use of that space is dependent on a number of factors. The reproductive state and social rank of females influence their range of space (Boydston *et al.*, 2003). The presence of cubs in dens influences the home range of female hyenas. Those with den-dependent cubs have smaller home ranges than those without, who travel further to reduce resource competition. Females of lower rank without cubs range the farthest, especially in times of nutrition scarcity (Boydston *et al.*, 2003). The use of dens by hyenas ties them to a specific location and home range, unlike lions that do not use dens and roam widely. The average distances travelled by hyena over 24 hours is 12.4km. Den use patterns have been reported to be altered in areas of high human activity, with lower activity and den use recorded during times of high disturbance, especially due to livestock herding (Kolowski *et al.*, 2007). The distance covered by hyena in a 24-hour period, combined with their abundance in miombo woodland and likelihood to follow a track that the field team also travel, may be causal factors in them being detected significantly more often on transect surveys than radial surveys.

4.3. Critique of study methodology.

Due to the nature of the field regime, following the requirements set out by the larger project centred primarily around mosquito ecology (Kavishe *et al.,* 2023), the survey methods employed here were somewhat distinctive. Although both transect and radial surveys of wildlife have been deployed many times in wildlife assessments, this study took the approach of carrying out both in parallel, alternating approach every second day so they can be directly compared. Many transect surveys employ distance sampling techniques, in which both the distance of the animal from the path travelled and the angle of detection from the path is recorded. While this can enable the investigators to estimate the total abundance of populations of species within a given area (Buckland *et al.*, 2001), this was considered an unrealistic ambition for this study *a priori*, for a number of reasons that proved to be correct. In hindsight, 1) dense vegetation in miombo woodlands compromises visual detectability, especially for smaller and more cryptic species of which there were very few direct observations. 2) Low rates of visual observation exacerbated by a necessarily large group for shared mosquito and wildlife surveys on radial surveys and moving camp during transect surveys. 3) Large contrast between the open areas on the borders between the villages outside ILUMA WMA and within the WMA, contrast sharply with the dense cover of the ground water forests within the WMA, leading to an imbalance in detectability throughout the study area. The limitation of this technique is that only direct sightings of animals are factored into the calculation of abundance. For the study reported herein, the determination of abundance of each species per se was therefore not the aim, but rather to detect species activity in relative terms and determine the influence of various forms of human encroachment. Therefore, this study combined detections of direct sightings with more common indicators of animal activity like tracks, spoor and other signs, with the aim to give a comprehensive overview of the wildlife activity ILUMA WMA and surveyed parts of NNP. These wildlife surveys were specifically designed to enable assessment of how the population composition of an important mosquito taxon that include several key malaria vectors varies with the relative abundance of various mammals, some of which could potentially be their preferred sources of blood.

Very few direct sightings were made throughout the course of this study (see Appendix 1), this could be due to a number of factors. The *degraded* areas of ILUMA WMA and the villages outside of its western border were quite open in terms of land cover, trees were sparse and bushes few when compared to the more ecologically intact areas. This lowers the probability of directly viewing live animals for two reasons, firstly these degraded habitats provide less cover for wildlife as they are more likely to be exposed to both humans and predators, ergo there were less animals to view in the first place, and secondly, the fact that these areas are open means that the wildlife can view the field team before the opposite occurs, allowing them time to flee and seek cover before a detection can be made and recorded by the observer. In contrast to the *degraded* camps, *pristine* areas of ILUMA WMA are often under the cover of dense miombo woodland or groundwater forest. Both of these habitats provide perfect cover for wildlife to avoid detection by the observer. A final factor to consider is the large field team that travelled on the surveys, by having more people, the noise emanating from the group increases even if each individual makes an effort to be quiet, due to footsteps on leaves, breaking branches etc. All of these factors considered, was justification for the surveys to include any sign of an animal as a detection, rather than only just a direct observation of a live animal. This survey type proved very successful in determining the relative activity of species of wildlife throughout ILUMA WMA from the degraded to the pristine areas and permitted comparisons with human activities to be made. It also proved valuable in associating specific wildlife species with specific mosquito taxon as detailed in Walsh *et al.* (forthcoming).

A study carried out on three different habitat types in Western Tanzania, employed the method of distance sampling described above, using closed circuit transects. By using habitat types as covariates for the probability of detection, researchers were successful in estimating both abundance and density of large herbivores (Waltert *et al.*, 2008). However, the aims of the aforementioned study and the one reported herein differed slightly, so the methodology also differed. Furthermore, line-transect sampling of live animals requires three assumptions to be met (Burnham, Anderson and Laake, 1980): objects on the line sampled will never be missed by all observers, objects are fixed in original sighting position, remain stationary until detected and are counted once only and that angles and distances are measured accurately. These assumptions would have been difficult to meet in the study area as species on the transect line could easily have been missed due to both dense undergrowth and tree cover, also it could not be guaranteed that the animal would not move before it was detected, therefore rendering this method unsuitable as none of the three criteria could be guaranteed with a degree of consistency. Fewster *et al.*, (2008) also found issues with the mobility of animals when carrying out line transect sampling particularly in highly mobile species. Other issues can arise with this method when there is a superabundance of animals readily detectable – the opposite of ILUMA WMAs situation. One example is an Australian study on Macropods using line-transect sampling that found the assumptions unachievable during data collection, the superabundance of animals in an open area prevented accurate counts (Southwell, 1994). Emphasising that distance transect sampling has known limitations in both areas where animals are well concealed, as they were in this study, and/or where animals are highly abundant in large groups in open areas.

The advantage of indirect methods for surveying animal activity has been established for some time (Wilson and Delahay, 2001) and they have been used effectively in a variety of environments. For example, animal tracks in snow provide valuable population distribution information on seasonal use, but is constrained to areas with year round snow cover (D'Eon, 2001). Fortunately, the given survey area has substrate types that are better suited to monitoring species distribution patterns over season, albeit with obvious variability that is difficult to account for. In Tanzania, track and dung surveys are commonly employed as they work reasonably well in a wide variety of different environments, and have been used to supplement transect surveys in areas with poor detectability (Rovero and Marshall, 2004). For example, a study carried out in the Kilombero valley used a combination of tracks and spoor to monitor the effect of land-use change on *Bovidae* (Jenkins *et al.*, 2002).

Finally, it is important to highlight why radial surveys proved to be the most sensitive and powerful method for recording detections of wild animals in this study. Almost 90% of all the species that featured in this study were more frequently detected during radial surveys centred around waterbodies than transect surveys undertaken on hikes between camps (see Figure 34). There is an advantage in sampling waterholes as opposed to dry land transects if determining the absolute abundance of species was the end goal, as most animals require surface water for survival and therefore were detected most often on radial surveys, the few species that don't usually take advantage of it on a facultative basis were detected more in transect surveys, although differential sensitivity between species will distort relative activity estimates toward more water dependent species. The majority of species that were detected more frequently by radial surveys are water-dependent, and/or prefer moister habitats, with good cover around water sources. Waterbuck, bushbuck and hippopotamus are all heavily water dependent. Elephant, although they have the ability to survive for days without water, choose to drink and bathe in waterholes daily whenever the opportunity arises (Estes, 2012). Reedbuck preferentially use the grasslands associated with drainage lines, and buffalo prefer dense cover such as reeds, woodlands, forests and thickets around waterbodies while water mongoose find their prey in such waterbodies. When reviewing the two survey methods, both were potential options in terms of fitting into a logistically feasible field routine and the radial surveys around water bodies that malaria vectors also breed in, provided invaluable complementary data for the mosquito ecology studies undertaken by Walsh *et al.,* (forthcoming) and Kavishe *et al.,* (forthcoming). However, the clear contrast in detectability of species between two survey types should be considered in future studies in similar miombo woodland habitat. Transect surveys in the manner used here, have the advantage of being carried out during transit from one location to the next, this can be easier to sustain long term or fit into future studies, as it requires a short resting period between surveys or a maximum stay of one night in one location. On the contrary, radial surveys require a longer time to be spent in the field as the radius around each camp is surveyed, and the distance to the new location must be travelled after this. The sensitivity of radial surveys was clearly greater for the majority of species featuring in this study; however, the long-term cost-effectiveness of radial surveys needs to be critically considered in future research studies and routine monitoring surveys. The VGS regularly undertake patrols throughout ILUMA WMA, covering large distances each day, perhaps incorporating transect surveys into their routine could prove an efficient way to monitor both wildlife and human activity throughout the WMA. Given the unsuitability of line transect sampling using direct sightings of wildlife only, combined with the suitability of track and spoor surveys for the given environment, the survey techniques chosen here are reasonably supported.

4.4. Assessing the ecological integrity of each location.

In agreement with the formal statistical results, it was apparent from personal observations made during fieldwork, that there may be a trend in the level of human encroachment and land degradation as one moves from west to east across the study area, and as the conservation status of the land changes from unprotected to WMA to national park (see Figure 36).

Two distinct camp clusters were apparent from the data collected (see Figure 35), it appears as if the level of unauthorised human activity and subsequent ancillary activities that consequently degrade the land were driving clustering. This cluster analysis, combined with the camps geographic location (outside ILUMA WMA, inside ILUMA WMA or NNP) provided a sound categorical framework for more careful consideration of the status of each camp on an individual basis. It was obvious from such descriptive assessments thirty of the camps fitted into two distinctive clusters that could be readily assigned an intuitive meaning based on the distributions of values for the variables used to resolve them, as well as informal observations made during fieldwork. However, it was not immediately apparent as to why camps 15 (*Mdalangwila*) and 27 (*Bwawa la Mlenda*) were placed in the *degraded* cluster, as both appeared to be mostly ecologically intact during data collection, and high levels of unauthorised human activity were not observed at either camp. The reason for their cluster designation became apparent after discussion with VGS, however. *Bwawa la Mlenda* acts as a covert entry route for timber poachers to enter ILUMA WMA, and the chairperson of *Mdalangwila* was described as somewhat uncooperative by the VGS, allowing some unauthorised activity to go unreported. It is evident to see here how statistically objective cluster analysis of formally recorded survey data identified patterns in the data that were not obvious to the researcher, prompting valuable, informal qualitative investigation into areas of the WMA.

In order to visualise more fine scale variation between camps and rank them accordingly, suitable measurements had to be selected. Deciding on appropriate measures to assess species diversity and human encroachment in study sites proved difficult as "diversity" is defined by the index used to measure it (Peet, 1974) and does not have one clear definition in ecology. It is for this reason that five different indices were chosen to rank each camp and create a comprehensive summary of the conditions at that location.

Obtaining both a SRI and a SID score for each camp permitted them to be ranked according to richness and diversity, but, a third composite index was employed to portray an alternative picture of the animal community at each location based on formally collected data. Objective Natural Animal Community Integrity Index (ONACII) is a PCA based index. Using PCA to establish the composition of an animal community is seen widely in ecological literature, and was first used in plant ecology and numerical taxonomy (James and McCulloch, 1990). While many studies have focussed on using PCA for its primary purpose of reducing strongly correlated data into groups, PCA has also been used in both the exploratory and analyses stages of studies on environmental variation, habitat suitability and niche partitioning (Janžekovič and Novak, 2012). Its applications can be seen in examples such as the ecological integrity of a stream macroinvertebrate community was evaluated at different sites in a river catchment in central Portugal (Castela, Ferreira and Graça, 2008) and microarthropod communities were linked to different land use types in the Po valley (Menta *et al.*, 2011). The results of ONACII reported here, show that the number of human activities that impact upon this index are comparable with the two non-PCA based animal indices (SRI and SID). This index, however, was the only index of the five tested in which meat poaching was significant, and provided quite a different ranking order of locations, therefore ONACII provides an alternative picture to the other two animal – only indices.

PCA has also been used to determine indices of ecological integrity or vulnerability on different scales in other studies, such as being the final step in calculating a regional index of ecological integrity (Reza and Abdullah, 2011) and selecting the most important indicators when comprising an ecological integrity index for wetlands in agricultural catchments (Ortega *et al.*, 2004). One study (Caniani *et al.*, 2016) assessing the differences in ecological vulnerability between fragmented sites of community and ecological importance in Italy, combined PCA with fuzzy logic to create an index to help to determine which sites are most ecologically vulnerable and need to be protected first (Caniani *et al.*, 2016). While similar to the current study in terms of encompassing both ecological and anthropogenic impacts into the index, Caniani *et al.* (2016) go beyond in using that index as the single tool used in assessing site's vulnerability to help conservation decision making processes. The common thread between these three examples and the current study that used a PCA-based ecological integrity index (ONEII), is that PCA has been a useful tool in differentiating between sites for comparison.

Overall, SNEII appears to be a reasonable, convenient, holistic and cost-effective substitute for the four objective alternatives, all of which rely on expert analyses of large amounts of laboriously collected formal quantitative survey data. As SNEII and ONEII both aimed at combining observations of wildlife, livestock and human activities, together with land cover attributes, to grade each of the camp locations, the reassuring correlation between these two conceptually similar indices was particularly reassuring with respect to the validity of the former as a potential substitute for the latter. Indeed, beyond being an apparently adequate substitute for these measures with no obvious disadvantages, it may well be a more sensitive and powerful indicator of encroachment by people and their livestock than any of the objective alternatives. This latter observation is consistent with the experiences of other investigators all across the tropics, who report that use of such subjective, intuitive indicators can provide many insights into ecosystem state and functionality, not to mention conservation intervention opportunities, that would have been missed if they had relied solely upon purely objective, formal, quantitative methodologies (Raddaoui, 2009; Vergara-Asenjo *et al.,* 2015; Beaudoin et al., 2016). Indeed, beyond yielding more detailed analytical insights into ongoing conservation successes, failures and opportunities in this southern Tanzanian WMA. SNEII also proved to be a powerful environmental predictor of the malaria vector mosquito population composition across the same study area (Walsh, forthcoming).

In stark contrast with the SNEII, all four objective alternatives required large amount of survey data and numerical expertise to estimate, neither of which may be available, or indeed appropriate in all contexts where the ecological integrity of an area needs to be established quickly and affordably. Indeed, SNEII represents an intuitive approach to expressing consensus subjective perceptions, permitting rapid determination of a location's status in approximate semi-quantitative terms, without requiring any numerical data or statistical knowledge. Scoring of an SNEII requires only that the individuals responsible for scoring this index have reasonable understanding of the ecosystem in question. For example, all three investigators who ranked these camps as described herein, were all master's degree candidates with no prior experience of comparable habitats. Indeed, community-based professionals with especially relevant in-depth informal expertise, like the VGS who supported this study, may well prove to be ideal observer-investigators in more participatory applications of the same approach in due course. If this proves to be the case, it may be broadly useful for larger scale application in sustained, long-term conservation monitoring, as distinct from time-limited research projects like this study, because it produces rapid, affordable, practical and meaningful assessments of ecosystem status. One of the greatest advantages of this index is that it produces a holistic composite score based on all recorded parameters and unrecorded personal impressions of the ecosystem that may be readily interpreted on an intuitive basis and may be discussed with a variety of stakeholders in conservation areas, notably in the communities living in or alongside them.

Some possible caveats to be considered when adapting this new perception-based approach, however, relates to areas where there is either considerably more, or considerably less unauthorised human activity and land degradation. For example, the study area of this project involved areas ranging from fully domesticated villages and farmland all the way through to fully pristine lands inside NNP. The responsible investigators found that the inclusion of such survey sites outside the WMA, at both extremes of the full possible spectrum of natural ecosystem integrity, helped them greatly in assigning a score because they provided obvious gold standards with which locations exhibiting a kaleidoscope of different intermediate characteristics within ILUMA could be intuitively compared. In more homogenous areas, where a gradient isn't so stark and fully domesticated or pristine areas are lacking, it may prove more difficult to assign reliable scores. Where possible, it may therefore be wise to similarly extend survey sampling frames for other conservation areas slightly beyond their boundaries, to include locations on either end of the degraded-to-pristine spectrum that provide observers with similar points of reference at both extremes.

When assessing the ecological integrity of each location, numerous camps achieved the same score on SRI, and therefore had the same rank value, but when comparing the camps ranked in the top third for all three animals-only indices some trends emerge (see Table 5). Three camps *Bwawa la Nyati* (camp 3)*, Bwawa la Chamvi* (camp 9) and *Bwawa la Moto* (camp 32) are all consistently in the top ranks for these indices. Given that two of these camps are located inside ILUMA WMA, this is a good indication that the camps that experience minimal unauthorised human activity score well on animal community indices. As SRI and SID both share a richness component in how they are calculated, it would be expected that these indices would produce the most similar ranks. This appeared true, as far more similarities were detected between SRI and SID than between these two and ONACII. *Korongo la Bundu* (camp 5), *Bwawa la Njuju* (camp 8), *Mikeregembe* (camp 14) and *Mdalangwila* (camp 15) all ranked in the top camps for both SRI and SID. It is extremely encouraging that these camps are all located in ILUMA WMA. The contrast between these similarities and camps ranked in the top third for ONACII is quite obvious. All four of the NNP camps feature in ONACII top ten, as well as two ILUMA camps that don't rank highly in SRI or SID – *Bwawa la Miembeni* (camp 10) and *Bwawa la Semka* (camp 28). A similar pattern appeared when comparing the worst ranked camps of the three indices. All six of the fully domesticated villages outside of ILUMA's western border were ranked as the bottom six camps in SRI and SID. Just two villages *Kisaki* (camp 22) and *Uwanja wa Ndege* (camp 23) were ranked in the bottom six of ONACII. Highly degraded camps inside ILUMA but close to the western boundary were scored worse than the remaining villages by this index. By evaluating both the similarities and differences of these three indices, a holistic picture of the state of the animal community was established (see Table 5 and Figures 37, 38 and 40).

As previously discussed, SNEII and ONEII are highly correlated. The top four camps in both indices are located in NNP and the lowest ranked camps are all fully domesticated villages or highly degraded areas inside ILUMA WMA. When comparing all indices across all camps it is thought-provoking to note that the camps that scored the best in terms of their whole ecological state, based on indicators of wildlife and encroachment activities combined, didn't score as well for indices the animal community only. As was expected, the level of unauthorised human activity in NNP was much lower than ILUMA WMA, due to both its more rigorous conservation status and its distance from areas of human settlement, and accordingly these camps receive higher scores for the integrity of the ecosystem as a whole.

For NNP camps to score lower in two of the three animal - only indices (see Table 5) is most likely due to the habitat type differences between ILUMA WMA and NNP. ILUMA hosts different habitat types from degraded miombo woodland to areas of both open and dense miombo woodland, dense groundwater forests, in addition to riparian habitat, ephemeral waterbodies and open glades with rich moist soils and perennial green grasses. While NNP also contains considerable areas of both dense and open miombo woodland, it is overall a much drier landscape with acacia savanna dominating throughout. The mosaic of habitats in ILUMA enables it to support a large diversity of wildlife and provides interconnectivity between multiple ecosystem types. In this way it cannot only support an abundance of species, but it can also provide refuge to species from NNP during times of the year when resources are not as plentiful such as in the dry season when surface water and short-green grasses are more difficult to find, especially in the acacia savanna areas of NNP.

4.5. Impacts of unauthorised human activities on ecological indices.

While the results of each of the five indices of natural animal community or overall ecosystem intactness differ, there was a clear advantage to using all of these as complementary alternative dependent variables with which to assess the impacts of various human activities. The most influential human activity on all of the ecological indices used in this study was livestock herding (see Tables 6, 7 and 9, and Figures 44, 45 and 53.

Livestock herding was the only human activity that had a significant impact on SRI. SID, however, was also negatively impacted by unauthorised fishing (see Figure 46) and was the only index upon which this human activity had a negative effect. In addition to livestock herding, ONACII scores were also lowered by the occurrence of meat poaching (see Figure 54). Notably, this was the only index affected by meat poaching, which was detected at low frequencies throughout the survey area. In general, the animal community indices are most effected by livestock herding and some other small-scale extractive activities. It should be noted that human settlement per se did not have a substantially attributable effect on any of these animal community indices and that bodes well for conservation, especially as pressure for land becomes increasingly heightened.

Finally, SNEII was the ecological index that was associated with by far the greatest number of human activities, revealing that it is the most sensitive and statistically powerful of these indices for quantifying the effects of various forms of human encroachment (see Table 8). Livestock herding, human settlement, rice farming and other tillage crop farming were all associated with a negative effect on this index, most likely due to the level of land clearance and degradation involved with these activities. Human settlement was not considered to be a problem in itself, so long as the associated livelihoods had negligible impacts on the terrestrial ecosystems. Indeed, even the positive associations with charcoal burning and timber harvesting in multivariate analyses make sense if one interprets these patterns in terms of reverse causality. These positive associations do not reflect a positive impact of these human activities on the index, but instead it offers some indication of the land type affected most by the index. Charcoal burning and timber harvesting were most frequently recorded in areas of dense miombo woodland that were at least partially intact. These activities were not recorded in highly degraded areas as there were not many trees remaining that were suitable for these activities. Therefore, charcoal burning and timber harvesting usually take place in areas that rank highly in terms of ecological intactness and animal community richness and diversity.

Overall, livestock herding has proved to be the single greatest threat to species richness, diversity, and ecological integrity in ILUMA WMA during the course of this study, but it was also the unauthorised human activity detected most frequently. It should be cautioned that an increase in any other unauthorised human activity may have a similar effect, but this impact was not detected during this study as other unauthorised human activities were detected at much lower magnitudes when compared to livestock herding.

4.6. Suggestions for future studies and management.

As discovered through analyses of data collected in the manner described in section *2.1.3*, the way in which cattle herding is recorded for future studies may be improved and not require as complex transformations as had to be taken in this study. If cattle herding is detected, it is suggested that it is recorded twice, once as an activity and then again as livestock where the number of cattle are recorded, as opposed to what was done here, whereby cattle herds of 11 individuals or more were recorded as an activity, and groups of ten or less were just recorded as livestock.

A suggested, sustainable long-term solution for ILUMA WMA, rather than physical barriers, is frequent patrols and enabling the stakeholder community to safeguard the space for the mutual benefit of both local residents and wildlife. Where management is in place WMA model works well in ILUMA and a clear positive impact was noted in the authorised areas of human settlement on the banks of the Kilombero especially. As discussed, the presence of human settlement within the conservation area itself it not an issue in terms of ecological integrity and wildlife relative abundance and diversity. Areas of clearly defined settlement with sustainable, small-scale extraction livelihoods, that are accessed on a conditional basis, have shown to benefit wildlife communities during this survey, highlighting that when the land use plan is properly adhered to both local communities and wildlife can thrive. Fourteen villages have agreed to be part of this WMA and given a portion of their land for inclusion. With this action comes a willingness in these local people bordering a precious natural resource to conserve the land by adhering to agreed upon land use plans. However, from observations made during the course of this study, on the level of unauthorised human activities and lack of clear management for many years (Tarimo *et al.,* Unpublished) in ILUMA WMA, it was apparent that the residents of the villages surrounding the WMA have lost some faith in the model, but with increased involvement from village-level representatives in decision making processes, and tangible benefits to their local economies and the ecological status of the WMA, the land use plan for ILUMA should be very beneficial to both economic and conservation objectives in the future. The residents of the villages directly bordering ILUMA can act as its best asset and a line of defence in keeping it managed correctly if adequately enabled.

In summary, the land use plans formally agreed upon by the local stakeholder community are largely not being adhered to in ILUMA WMA, albeit with some important exceptions that may inform the development of a practical solution. Unauthorised human activities were frequently detected, and the results of analyses display the negative impact these activities, especially livestock herding, are having on local wildlife populations and on the ecological integrity of the system as a whole. A clear gradient in the level of land degradation from west to east was apparent, with the western and southern boundaries being most subjected to unauthorised human activity. While wildlife populations were recorded in the degraded areas of ILUMA WMA, the longer-term impacts of human encroachment should be cautioned. Degraded habitats host modest densities of wild animals, but these may not necessarily be self-sustaining and are likely propped up by high levels of immigration. Some specific species of animals that are relatively abundant in these areas can adapt adequately to local conditions, but most other wild species require more pristine habitats with minimal human encroachment. While these degraded areas act as a transition zone between ideal habitats and completely unsuitable areas, the animal community in these areas are typically marginal in terms of their viability (Kawecki, 2008). Correspondingly, if further degradation occurs across ILUMA, this transition zone becomes larger and a more unsuitable habitat for most wildlife species, notably those from neighbouring NNP that depend on it during the dry season. ILUMA WMA, even in its current partially degraded state is nevertheless acting as a vital buffer zone and dry season refuge for wildlife populations in nearby parts of NNP. Ongoing efforts to protect and enhance this WMA are crucial to ensure that CBC can succeed in this area, so that and both local people and wildlife benefit from the governance and management model.

5. Conclusions.

Data collection in ILUMA WMA detected more signs of wildlife activity for the majority of species surveyed when using radial surveys compared to transect surveys, so, this latter procedure may be optimal for surveying relative abundance and diversity. Advantages of this survey type include the way it samples distinct and convenient locations that attract most animal species and locations are far enough apart to be considered spatially independent in statistical terms. Also, the observation that it detected more species than transect surveys over the course of this study indicates that radial surveys may prove fruitful for future studies and when relative abundance and diversity are the aims of a study, this survey type may be optimal. The ecology of greater kudu, sable and hyena provide explanations for why they represent exceptions to the general rule that radial surveys around water sources are more sensitive for most species, indicating that transect surveys may be the better option for studies focussing primarily on one or more of these species.

A clear pattern in reduction in diversity and relative abundance of wildlife with increased unauthorised human activities was observed across the study area. Unauthorised human activities were found to be widespread in ILUMA WMA, especially across the western and southern areas. Unauthorised cattle herding, charcoal burning, farming, human settlement and timber harvesting were frequently recorded in the WMA, contrary to land use plans agreed with the relevant communities. Analyses undertaken and reported in this study reveal that cattle herding was the most commonly detected unauthorised human activity in ILUMA in 2022 and had the single greatest negative impact on all of the animal community and ecological integrity indices tested. A wet season grazing access plan, similar to that first suggested by local pastoralist communities over 20 years ago, when the area was still under centralised government management (Brehony *et al.,* 2001) might represent an option for formalising and regulating what currently amounts to rampant unauthorised cattle herding within the conservation area, potentially providing livelihoods and protecting wildlife populations within ILUMA WMA. A feasibility assessment into this is recommended, as unauthorised cattle herding is currently the single greatest threat to wildlife within the WMA, so the negative effects associated with cattle herding might be reduced to acceptable levels by regulating and managing it in a manner similar to the activities of the fishing camps that appear to bolster conservation practice.

Greater enforcement of the land use plan in ILUMA WMA is also recommended to reduce the number of occurrences of other unauthorised activities, such as deforestation for timber, building materials or charcoal production. A 2011 study found that deforestation in the Kilombero wetlands due to wood fuel consumption was causing a net deforestation of 3.4 to 21.6 hectares per day (Mombo *et al.*, 2011), and if current practices continue at the current rate within the wetlands of the Kilombero valley, just 37% of the natural vegetation will remain by 2030 (Proswitz *et al.*, 2021). This is unsustainable and exacerbates pressure on the surrounding ecosystem of the valley, including ILUMA.

The novel Subjective Natural Ecosystem Integrity Index (SNEII) proposed here and in Walsh *et al.,* (forthcoming), was highly correlated to a PCA –based Objective Natural Ecosystem Integrity Index (ONEII) described herein, so the former may offer a useful new option for routine ecosystem monitoring in the future, because it is affordable, practical and can be readily applied by the VGS or similar personnel during regular patrols, or by the local community members using participatory citizen science approaches.

The findings of this study reveal that where the land use plan developed and agreed with local communities was adhered to and monitored correctly, ILUMA WMA succeeded in protecting both the livelihoods of local communities and the conservation wildlife populations. This study has also revealed that human settlement itself within a conservation area is not necessarily detrimental to wildlife populations and may even improve them as was reported here in the authorised and carefully monitored fishing camps. Instead, it is the ancillary activities that associated with unauthorised and unregulated encroachment by people, such as land clearing and cattle herding, that negatively affect wildlife populations.

Reflecting on the success stories of another CBC organisation in northern Tanzania that initially struggled, specifically Burunge WMA, where increasing community participation in governance and management resulted in heightened enforcement of their land use plan, there are grounds for optimism about the future of ILUMA WMA if current efforts to devolve management and improve enforcement of regulations prove successful. This, combined with the ongoing expansion of the REGROW programme to both develop tourism infrastructure and facilitate community-based tourism in southern Tanzania, represent encouraging opportunities for ILUMA WMA to continue its conservation efforts and achieve sustainability through increased revenue from tourism.

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Appendix.

Appendix 1. Total frequencies and mean frequencies for various sightings, tracks, spoor and other signs of humans, livestock, and wild animals per camp radial survey and per transect survey segment. Estimated means and 95% confidence interval are based on generalised linear mixed models assuming a Poisson distribution for the dependent variables and treating camp number as a random effect, fitted using the penalised quasi-likelihood procedure with the *glmmPQL* package in R.

Activity	Camp Surveys (N =76)		Transect Survey Segments (N = 616)	
	Total $\sum_{i=1}^{N} \bar{n}_i$	Mean [95% CI] $\bar{n}_i$	Total $\sum_{i=1}^{N} \bar{n}_i$	Mean [95% CI] $\bar{n}_i$
Humans				
Community Members Present Outside Conservation Area				
Direct Sighting	708	9.36 [7.58, 11.55]	461	0.723 [0.605, 0.863]
Tracks				
Active	0	0.00 [NE]	9	0.015 [0.006, 0.037]
Recent	3	0.04 [<0.01 0.36]	2	0.003 [<0.001, 0.023]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	3	0.04 [<0.01, 0.36]	11	0.018 [<0.001, 0.060]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	711		472	
Authorised Community Members Present Inside Conservation Area				
Direct Sighting	115	1.52 [1.03, 2.24]	173	0.285 [0.224, 0.362]
Tracks				
Active	2	0.03 [0.00, 0.40]	48	0.079 [0.052, 0.119]
Recent	2	0.03 [0.00, 0.40]	35	0.058 [0.036, 0.093]
Old	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Total	4	0.06 [<0.01, 0.79]	85	0.140 [0.088, 0.235]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]

Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	119		258	

Unauthorised Community Members Present Inside Conservation Area

Direct Sighting	215	2.84 [2.10, 3.85]	172	0.283 [0.223, 0.360]
Tracks				
Active	29	0.38 [0.19, 0.79]	65	0.107 [0.075, 0.153]
Recent	18	0.24 [0.10, 0.59]	86	0.142 [0.103, 0.195]
Old	2	0.03 [<0.001, 0.39]	1	0.002 [<0.001, 0.026]
Total	49	0.65 [0.28, 1.78]	152	0.251 [0.178, 0.374]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Total	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Other Signs				
Active	7	0.09 [0.02, 0.40]	7	0.012 [0.004, 0.033]
Recent	6	0.08 [0.02, 0.38]	2	0.003 [<0.001, 0.023]
Old	8	0.11 [0.03, 0.41]	4	0.007 [0.002, 0.028]
Total	21	0.28 [0.07, 1.19]	13	0.022 [0.006, 0.084]
Overall Total	288		337	

Unauthorised Charcoal Burner

Direct Sighting	3	0.04 [<0.01, 0.36]	5	0.008 [0.002, 0.028]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	2	0.03 [<0.01, 0.40]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	2	0.03 [<0.01, 0.40]	1	0.002 [<0.001, 0.026]
Overall Total	5		6	

Unauthorised Charcoal Transport				
Direct Sighting	19	0.25 [0.10, 0.61]	7	0.012 [0.004, 0.033]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.60]	1	0.002 [<0.001, 0.026]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	1	0.002 [<0.001, 0.026]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.60]	1	0.002 [<0.001, 0.026]
Old	0	0.00 [NE]	5	0.008 [0.002, 0.028]
Total	1	0.01 [<0.01, 0.60]	6	0.010 [0.002, 0.054]
Overall Total	21		14	
Unauthorised Timber Harvesting				
Direct Sighting	4	0.05 [0.01, 0.36]	5	0.008 [0.002, 0.028]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	2	0.03 [<0.01, 0.40]	0	0.000 [NE]
Total	3	0.04 [<0.01, 1.00]	0	0.000 [NE]
Overall Total	7		5	
Unauthorised Timber Transport				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	3	0.04 [<0.01, 0.36]	0	0.000 [NE]

Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	3		0	

Unauthorised Fish Harvesting

Direct Sighting	22	0.29 [0.13, 0.67]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	22		0	

Unauthorised Fish Transport

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]

Overall Total	0		0	
ILUMA Personnel				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	1		0	
NNP Rangers				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	1	0.01 [<0.01, 0.60]	2	0.003 [<0.001, 0.023]
Recent	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	3	0.005 [<0.001, 0.049]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	1		3	
Hunting Company Staff				
Direct Sighting	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Tracks				
Active	0	0.00 [NE]	2	0.003 [<0.001, 0.023]

Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	0		3	

Other Authorised Personnel

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	0		0	

Livestock and Work Animals

Herds of 10 cattle or less

Direct Sighting	65	0.86 [0.33, 1.71]	12	0.020 [0.009, 0.044]
Tracks				
Recent	22	0.29 [0.13, 0.67]	55	0.091 [0.061, 0.134]
Old	24	0.32 [0.14, 0.70]	31	0.051 [0.031, 0.085]
Total	111	1.47 [0.60, 3.08]	98	0.175 [0.162, 0.263]

Herds of 11 cattle or more

Direct Sighting	181	2.39 [1.73, 3.30]	204	0.336 [0.268, 0.421]

Tracks				
Recent	69	0.91 [0.56, 1.48]	180	0.300 [0.234, 0.376]
Old	31	0.41 [0.21, 0.83]	95	0.156 [0.115, 0.212]
Total	281	3.71 [2.50, 5.61]	479	0.792 [0.617, 1.009]
Overall Cattle Total	392		577	
<u>Goat</u>				
Direct Sighting	5	0.07 [0.01, 0.37]	1	0.002 [<0.001, 0.026]
Tracks				
Active	15	0.19 [0.07, 0.54]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Old	0	<0.01	2	0.003 [<0.001, 0.023]
Total	16	0.20 [0.07, 1.14]	2	0.003 [<0.001, 0.023]
Spoor				
Active	1	0.01 [<0.01, 0.60]	1	0.002 [<0.001, 0.023]
Recent	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	2	0.02 [<0.01, 1.21]	1	0.002 [<0.001, 0.023]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	23		4	
<u>Sheep</u>				
Direct Sighting	3	0.04 [<0.01, 0.04]	3	0.005 [0.001, 0.024]
Tracks				
Active	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	3		5	
<u>Chicken</u>				

Direct Sighting	101	1.34 [0.86, 2.01]	115	0.189 [0.143, 0.251]
Tracks				
Active	0	0.000 [NE]	0	0.000 [NE]
Recent	0	0.000 [NE]	0	0.000 [NE]
Old	0	0.000 [NE]	0	0.000 [NE]
Total	0	0.000 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.000 [NE]	0	0.000 [NE]
Recent	0	0.000 [NE]	0	0.000 [NE]
Old	0	0.000 [NE]	0	0.000 [NE]
Total	0	0.000 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.000 [NE]	0	0.000 [NE]
Recent	0	0.000 [NE]	0	0.000 [NE]
Old	0	0.000 [NE]	0	0.000 [NE]
Total	0	0.000 [NE]	0	0.000 [NE]
Overall Total	101		115	

<u>Dog</u>

Direct Sighting	68	0.90 [0.55, 1.46]	27	0.044 [0.026, 0.076]
Tracks				
Active	121	1.60 [1.09, 2.34]	91	0.150 [0.110, 0.205]
Recent	26	0.34 [0.16, 0.74]	31	0.051 [0.031, 0.085]
Old	3	0.04 [<0.01, 0.36]	2	0.003 [<0.001, 0.023]
Total	150	1.98 [1.26, 3.44]	124	0.2041 [0.141, 0.313]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Old	7	0.09 [0.02, 0.40]	1	0.002 [<0.001, 0.025]
Total	8	0.10 [0.02, 1.00]	1	0.002 [<0.001, 0.025]
Other Signs				
Active	0	0.00 [NE]	1	0.002 [<0.001, 0.025]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	1	0.002 [<0.001, 0.025]
Overall Total	226		153	

<u>**Wild Herbivores**</u>

<u>Reedbuck</u>

Direct Sighting	1	0.01 [<0.01, 0.60]	10	0.016 [0.007, 0.039]
Tracks				
Active	78	1.03 [0.65, 1.63]	25	0.041 [0.023, 0.072]
Recent	9	0.12 [0.03, 0.43]	4	0.006 [0.002, 0.026]
Old	16	0.21 [0.08, 0.56]	1	0.001 [<0.001, 0.026]
Total	103	1.36 [0.76, 2.62]	30	0.048 [0.025, 0.124]
Spoor				

Active	23	0.30 [0.14, 0.68]	12	0.198 [0.009, 0.044]
Recent	15	0.20 [0.07, 0.54]	8	0.013 [0.005, 0.035]
Old	27	0.36 [0.17, 0.76]	31	0.051 [0.031, 0.085]
Total	65	0.86 [0.38, 1.98]	51	0.262 [0.045, 0.164]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	2	0.03 [0.00, 0.40]	0	0.000 [NE]
Total	2	0.03 [0.00, 0.40]	0	0.000 [NE]
Overall Total	171		91	
<u>Waterbuck</u>				
Direct Sighting	0	0.00 [NE]	23	0.038 [0.021, 0.068]
Tracks				
Active	55	0.73 [0.43, 1.24]	11	0.018 [0.008, 0.042]
Recent	17	0.23 [0.09, 0.57]	4	0.007 [0.002, 0.026]
Old	28	0.37 [0.18, 0.77]	0	0.000 [NE]
Total	100	1.33 [0.69, 2.59]	15	0.025 [0.010, 0.068]
Spoor				
Active	4	0.05 [0.01, 0.36]	5	0.008 [0.002, 0.028]
Recent	17	0.23 [0.09, 0.57]	16	0.026 [0.013, 0.053]
Old	28	0.37 [0.18, 0.77]	29	0.017 [0.008, 0.040]
Total	49	0.65 [0.27, 1.71]	50	0.051 [0.023, 0.121]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Overall Total	150		88	
<u>Puku</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	4	0.05 [0.01, 0.40]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Old	2	0.03 [<0.01, 0.40]	0	0.000 [NE]
Total	7	0.09 [0.01, 1.36]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]

Overall Total	7		0	
<u>Bushbuck</u>				
Direct Sighting	4	0.05 [0.01, 0.36]	0	0.000 [NE]
Tracks				
Active	63	0.83 [0.50, 1.38]	10	0.016 [0.007, 0.039]
Recent	6	0.08 [0.02, 0.38]	0	0.000 [NE]
Old	7	0.09 [0.02, 0.40]	0	0.000 [NE]
Total	76	1.00 [0.54, 2.15]	10	0.0164 [0.01, 0.04]
Spoor				
Active	4	0.05 [0.01, 0.36]	0	0.000 [NE]
Recent	3	0.04 [0.00, 0.36]	1	0.002 [<0.001, 0.026]
Old	3	0.04 [0.00, 0.36]	4	0.007 [0.002, 0.026]
Total	10	0.13 [0.02, 1.08]	5	0.009 [0.002, 0.052]
Other Signs				
Active	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Overall Total	93		15	
<u>Eland</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	11	0.15 [0.05, 0.46]	0	0.000 [NE]
Recent	3	0.04 [<0.01, 0.36]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Total	15	0.20 [0.05, 1.43]	0	0.000 [NE]
Spoor				
Active	4	0.05 [0.01, 0.36]	3	0.005 [0.001, 0.024]
Recent	29	0.38 [0.19, 0.79]	6	0.010 [0.003, 0.030]
Old	52	0.69 [0.40, 1.19]	32	0.053 [0.032, 0.087]
Total	85	1.12 [0.59, 2.34]	41	0.068 [0.035, 0.141]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	100		41	
<u>Greater Kudu</u>				
Direct Sighting	0	0.00 [NE]	20	0.033 [0.018, 0.061]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]

Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	1	0.01 [<0.01,0.60]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	2	0.05 [0.01, 0.36]	0	0.000 [NE]
Total	3	0.06 [0.01, 0.96]	1	0.002 [<0.001, 0.026]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Overall Total	4		21	
<u>Hartebeest</u>				
Direct Sighting	12	0.16 [0.05, 3.30]	21	0.035 [0.019, 0.064]
Tracks				
Active	181	2.39 [1.73, 1.11]	116	0.191 [0.144, 0.253]
Recent	47	0.62 [0.35, 0.85]	11	0.018 [0.008, 0.042]
Old	32	0.42 [0.21, 0.65]	9	0.015 [0.006, 0.037]
Total	260	3.43 [2.29, 2.60]	136	0.224 [0.158, 0.332]
Spoor				
Active	21	0.28 [0.12, 0.90]	38	0.063 [0.039, 0.099]
Recent	35	0.46 [0.24, 1.98]	95	0.115 [0.081, 0.163]
Old	99	1.31 [0.86, 0.37]	189	0.311 [0.246, 0.393]
Total	155	2.05 [1.22, 3.24]	322	0.489 [0.366, 0.655]
Other Signs				
Active	5	0.07 [0.01, 0.60]	1	0.002 [<0.001, 0.025]
Recent	1	0.01 [<0.01, 0.45]	0	0.000 [NE]
Old	10	0.13 [0.04, 0.60]	5	0.008 [0.002, 0.028]
Total	16	0.21 [0.05, 1.66]	6	0.010 [0.002, 0.053]
Overall Total	443		485	
<u>Wildebeest</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.40]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.40]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]

Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	1		0	
<u>Sable Antelope</u>				
Direct Sighting	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Tracks				
Active	7	0.09 [0.02, 0.36]	17	0.028 [0.014, 0.055]
Recent	4	0.05 [0.01, 0.40]	1	0.002 [<0.001, 0.026]
Old	2	0.03 [<0.01, 0.36]	0	0.000 [NE]
Total	13	0.17 [0.03, 1.11]	18	0.030 [0.014, 0.081]
Spoor				
Active	3	0.04 [<0.01, 0.36]	10	0.017 [0.007, 0.039]
Recent	3	0.04 [<0.01, 0.40]	4	0.007 [0.002, 0.026]
Old	2	0.03 [<0.01, 0.60]	4	0.007 [0.002, 0.026]
Total	8	0.11 [0.01, 1.36]	18	0.031 [0.011, 0.091]
Other Signs				
Active	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Overall Total	21		39	
<u>Warthog</u>				
Direct Sighting	1	0.01 [<0.01, 0.36]	3	0.005 [0.001, 0.024]
Tracks				
Active	4	0.05 [0.01, 0.50]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	4	0.05 [0.01, 0.50]	1	0.002 [<0.001, 0.026]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	13	0.17 [0.06, 0.38]	0	0.000 [NE]
Recent	6	0.08 [0.02, 2.68]	0	0.000 [NE]
Old	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Total	19	0.25 [0.07, 2.31]	1	0.002 [<0.001, 0.026]
Overall Total	24		5	
<u>Bushpig</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]

Tracks				
Active	142	1.88 [1.31, 1.06]	8	0.013 [0.005, 0.035]
Recent	44	0.58 [0.32, 0.65]	0	0.000 [NE]
Old	21	0.28 [0.19, 0.60]	0	0.000 [NE]
Total	207	2.74 [1.75, 2.31]	8	0.013 [0.005, 0.035]
Spoor				
Active	1	0.01 [<0.01, 0.50]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	5	0.008 [0.002, 0.028]
Old	13	0.17 [<0.01, 0.50]	1	0.002 [<0.001, 0.023]
Total	14	0.18 [0.06, 1.52]	7	0.012 [0.002, 0.077]
Other Signs				
Active	42	0.56 [0.30, 0.79]	2	0.003 [<0.001, 0.023]
Recent	29	0.38 [0.19, 0.65]	4	0.007 [0.002, 0.026]
Old	21	0.28 [0.12, 0.63]	0	0.000 [NE]
Total	92	1.22 [0.61, 2.07]	6	0.010 [0.002, 0.049]
Overall Total	313		21	
Hippopotamus				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	20	0.26 [0.11, 0.48]	6	0.010 [0.003, 0.030]
Recent	12	0.16 [0.05, 1.30]	3	0.005 [0.001, 0.024]
Old	58	0.77 [0.45, 0.46]	13	0.021 [0.010, 0.046]
Total	90	1.19 [0.62, 2.24]	22	0.036 [0.140, 0.100]
Spoor				
Active	11	0.15 [0.05, 0.48]	1	0.002 [<0.001, 0.026]
Recent	12	0.16 [0.05, 0.76]	15	0.025 [0.012, 0.051]
Old	27	0.36 [0.17, 0.60]	18	0.030 [0.015, 0.057]
Total	50	0.67 [0.27, 1.84]	34	0.057 [0.027, 0.134]
Other Signs				
Active	1	0.01 [<0.01, 0.37]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	5	0.07 [0.01, 0.45]	3	0.005 [0.001, 0.024]
Total	6	0.08 [0.01, 0.81]	3	0.005 [0.001, 0.024]
Overall Total	146		59	
Elephant				
Direct Sighting	10	0.13 [0.04, 1.41]	1	0.002 [<0.001, 0.026]
Tracks				
Active	65	0.86 [0.52, 0.85]	28	0.046 [0.027, 0.078]
Recent	32	0.42 [0.21, 3.53]	18	0.030 [0.015, 0.057]
Old	195	2.58 [1.88, 0.76]	168	0.277 [0.217, 0.353]
Total	292	3.86 [2.62, 5.13]	214	0.353 [0.259, 0.488]
Spoor				
Active	27	0.36 [0.17, 0.72]	17	0.028 [0.014, 0.055]
Recent	25	0.33 [0.15, 3.91]	52	0.086 [0.057, 0.126]
Old	219	2.89 [2.14, 1.07]	285	0.469 [0.383, 0.574]
Total	271	3.58 [2.46, 5.70]	354	0.583 [0.454, 0.755]

Other Signs				
Active	45	0.59 [0.33, 0.45]	10	0.016 [0.007, 0.039]
Recent	10	0.13 [0.04, 0.99]	4	0.007 [0.002, 0.026]
Old	40	0.53 [0.28, 0.60]	5	0.008 [0.002, 0.028]
Total	95	1.25 [0.65,2.04]	19	0.031 [0.011, 0.093]
Overall Total	668		588	
African Buffalo				
Direct Sighting	1	0.01 [<0.01, 1.90]	0	0.000 [NE]
Tracks				
Active	94	1.24 [0.81, 1.19]	83	0.137 [0.100, 0.190]
Recent	52	0.69 [0.40, 2.48]	7	0.012 [0.004, 0.033]
Old	130	1.72 [1.19, 0.36]	39	0.064 [0.041, 0.101]
Total	276	3.65 [2.40, 4.04]	129	0.213 [0.145, 0.324]
Spoor				
Active	4	0.05 [0.01, 0.48]	13	0.021 [0.010, 0.046]
Recent	12	0.16 [0.05, 2.65]	30	0.049 [0.030, 0.082]
Old	140	1.85 [1.29, 0.40]	81	0.133 [0.096, 0.185]
Total	156	2.06 [1.35, 3.52]	124	0.203 [0.136, 0.313]
Other Signs				
Active	2	0.03 [<0.01, 0.36]	1	0.0016 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	4	0.05 [0.01, 0.45]	2	0.003 [<0.001, 0.023]
Total	6	0.08 [0.01, 0.81]	3	0.0046 [<0.001, 0.049]
Overall Total	439		256	
Plains Zebra				
Direct Sighting	10	0.13 [0.04, 2.29]	25	0.041 [0.024, 0.072]
Tracks				
Active	118	1.56 [1.06, 0.56]	59	0.097 [0.067, 0.142]
Recent	16	0.21 [0.08, 0.67]	12	0.020 [0.009, 0.044]
Old	22	0.29 [0.13, 0.60]	7	0.012 [0.004, 0.033]
Total	156	2.06 [1.27, 1.83]	78	0.129 [0.080, 0.219]
Spoor				
Active	1	0.01 [0.00, 0.60]	1	0.002 [0.000, 0.026]
Recent	1	0.01 [0.00, 0.68]	4	0.007 [0.001, 0.026]
Old	23	0.30 [0.14, 0.60]	18	0.030 [0.015, 0.057]
Total	25	0.33 [0.14, 1.89]	23	0.039 [0.016, 0.109]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 1.24]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 1.24]	0	0.000 [NE]
Overall Total	192		126	
Suni				

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	55	0.73 [0.43, 0.36]	3	0.005 [0.001, 0.024]
Recent	3	0.04 [<0.01, 0.37]	0	0.000 [NE]
Old	5	0.07 [0.01, 0.60]	0	0.000 [NE]
Total	63	0.84 [0.44, 1.33]	3	0.005 [0.001, 0.024]
Spoor				
Active	0	0.00 [NE]	5	0.008 [0.002, 0.028]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	5	0.008 [0.002, 0.028]
Other Signs				
Active	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Overall Total	64		8	
<u>Common Duiker</u>				
Direct Sighting	1	0.01 [<0.01, 5.01]	3	0.005 [0.001, 0.024]
Tracks				
Active	289	3.82 [2.91, 0.63]	40	0.066 [0.042, 0.103]
Recent	20	0.26 [0.11, 0.63]	2	0.003 [0.001, 0.023]
Old	20	0.26 [0.11, 0.45]	0	0.000 [NE]
Total	329	4.34 [3.13, 1.71]	42	0.069 [0.043, 0.126]
Spoor				
Active	10	0.13 [0.04, 0.50]	1	0.002 [<0.001, 0.026]
Recent	13	0.17 [0.06, 0.45]	4	0.007 [0.002, 0.026]
Old	10	0.13 [0.04, 1.24]	16	0.026 [0.013, 0.053]
Total	33	0.43 [0.14, 1.31]	21	0.035 [0.015, 0.105]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Total	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Overall Total	363		67	
<u>Red Duiker</u>				
Direct Sighting	3	0.04 [<0.01, 0.37]	0	0.000 [NE]
Tracks				
Active	33	0.44 [0.14, 1.31]	0	0.000 [NE]
Recent	7	0.09 [0.02, 0.36]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	40	0.53 [0.16, 1.67]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]

Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	43		0	
Impala				
Direct Sighting	36	0.48 [0.25, 0.90]	1	0.002 [<0.001, 0.026]
Tracks				
Active	35	0.46 [0.24, 0.40]	19	0.031 [0.016, 0.059]
Recent	2	0.03 [<0.01, 0.40]	1	0.002 [<0.001, 0.026]
Old	2	0.03 [<0.01, 0.48]	0	0.000 [NE]
Total	39	0.52 [0.24, 1.27]	20	0.033 [0.016, 0.085]
Spoor				
Active	12	0.16 [0.05, 0.92]	7	0.012 [0.004, 0.033]
Recent	36	0.48 [0.25, 1.16]	20	0.033 [0.017, 0.062]
Old	50	0.66 [0.38, 0.95]	33	0.054 [0.033, 0.089]
Total	98	1.30 [0.68, 3.03]	60	0.099 [0.054, 0.184]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Overall Total	174		81	
Dikdik				
Direct Sighting	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Tracks				
Active	38	0.50 [0.27, 0.40]	6	0.010 [0.003, 0.030]
Recent	2	0.03 [<0.01, 0.60]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	40	0.53 [0.27, 1.00]	6	0.010 [0.003, 0.030]
Spoor				
Active	1	0.01 [<0.01, 0.41]	2	0.003 [<0.001, 0.023]
Recent	8	0.11 [0.03, 0.40]	8	0.013 [0.005, 0.035]
Old	7	0.09 [0.02, 0.40]	5	0.008 [0.002, 0.028]
Total	16	0.21 [0.05, 1.21]	15	0.024 [0.007, 0.086]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	56		23	

Sharpe's Grysbok

Direct Sighting	2	0.03 [<0.01, 0.77]	1	0.002 [<0.001, 0.026]
Tracks				
Active	28	0.37 [0.18, 0.40]	3	0.005 [0.01, 0.024]
Recent	2	0.03 [<0.01, 0.60]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.60]	0	0.000 [NE]
Total	31	0.41 [0.18, 1.60]	3	0.005 [0.01, 0.024]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	33		4	

Wild Rodents

Porcupine

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	3	0.03 [<0.01, 0.14]	7	0.012 [0.004, 0.033]
Recent	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	5	0.05 [0.01, 0.26]	7	0.012 [0.004, 0.033]
Spoor				
Active	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Recent	1	0.01 [<0.01, 0.12]	4	0.007 [0.002, 0.026]
Old	1	0.01 [<0.01, 0.12]	8	0.013 [0.005, 0.035]
Total	2	0.02 [<0.01, 0.25]	13	0.022 [0.007, 0.087]
Other Signs				
Active	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Recent	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	4	0.04 [0.01, 0.25]	0	0.000 [NE]
Overall Total	11		20	

Giant Cane Rat

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				

Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Overall Total	2		0	

Wild Carnivores

<u>Lion</u>

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	6	0.07 [0.02, 0.18]	6	0.0010 [<0.001, 0.028]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	3	0.03 [0.01, 0.14]	0	0.000 [NE]
Total	9	0.10 [0.03, 0.32]	6	0.0010 [<0.001, 0.028]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	9		6	

<u>Leopard</u>

Direct Sighting	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Tracks				
Active	6	0.07 [0.02, 0.18]	0	0.000 [NE]
Recent	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Old	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Total	6	0.07 [0.02, 0.18]	3	0.005 [<0.001, 0.049]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Old	7	0.08 [0.03, 0.20]	5	0.008 [0.002, 0.028]

Total	8	0.09 [0.03, 0.32]	5	0.008 [0.002, 0.028]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Overall Total	15		9	
<u>African Wild Cat</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	40	0.44 [0.28, 0.71]	16	0.026 [0.013, 0.053]
Recent	8	0.09 [0.04, 0.22]	3	0.005 [0.001, 0.024]
Old	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Total	50	0.55 [0.32, 1.05]	19	0.031 [0.014, 0.077]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Old	8	0.09 [0.04, 0.22]	4	0.007 [0.002, 0.026]
Total	8	0.09 [0.04, 0.22]	5	0.009 [<0.001, 0.052]
Other Signs				
Active	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Overall Total	60		24	
<u>African Civet</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	8	0.09 [0.04, 0.22]	5	0.008 [0.002, 0.030]
Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	10	0.11 [0.04, 0.46]	5	0.008 [0.002, 0.030]
Spoor				
Active	5	0.06 [0.02, 0.17]	0	0.000 [NE]
Recent	0	0.00 [NE]	5	0.008 [0.002, 0.028]
Old	2	0.02 [<0.01, 0.12]	5	0.008 [0.002, 0.028]
Total	7	0.08 [0.02, 0.29]	10	0.016 [0.002, 0.056]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	2	0.02 [<0.01, 0.25]	0	0.000 [NE]
Overall Total	19		15	
<u>Genet</u>				

Direct Sighting	0	0.00 [NE]	2	0.003 [<0.001, 0.023]
Tracks				
Active	7	0.08 [0.03, 0.20]	4	0.007 [0.002, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	8	0.09 [0.03, 0.32]	4	0.007 [0.002, 0.026]
Spoor				
Active	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	2	0.02 [<0.01, 0.25]	1	0.002 [<0.001, 0.026]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	10		7	
Spotted Hyena				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	25	0.28 [0.16, 0.48]	22	0.036 [0.020, 0.066]
Recent	6	0.07 [0.02, 0.18]	4	0.007 [0.002, 0.026]
Old	3	0.03 [0.01, 0.14]	0	0.000 [NE]
Total	34	0.38 [0.19, 0.80]	26	0.043 [0.022, 0.091]
Spoor				
Active	1	0.01 [<0.01, 0.12]	1	0.002 [<0.001, 0.026]
Recent	1	0.01 [0.00, 0.12]	0	0.000 [NE]
Old	5	0.06 [0.02, 0.17]	46	0.076 [0.050, 0.115]
Total	7	0.08 [0.02, 0.41]	47	0.078 [<0.001, 0.141]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	41		73	
African Wild Dog				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]

Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	
Overall Total	0		0	

<u>Side – Striped Jackal</u>

Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	3	0.03 [0.01, 0.14]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	3	0.03 [0.01, 0.14]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	3		0	

<u>Slender Mongoose</u>

Direct Sighting	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Tracks				
Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	2		0	

<u>Banded Mongoose</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Total	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Other Signs				
Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Overall Total	4		0	
<u>Water Mongoose</u>				
Direct Sighting	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Tracks				
Active	95	1.08 [0.74, 1.58]	22	0.036 [0.020, 0.066]
Recent	41	0.45 [0.28, 0.73]	1	0.002 [<0.001, 0.026]
Old	8	0.09 [0.04, 0.22]	1	0.002 [<0.001, 0.026]
Total	144	1.62 [1.06, 2.52]	24	0.040 [<0.001, 0.118]
Spoor				
Active	11	0.12 [0.06, 0.26]	2	0.003 [<0.001, 0.023]
Recent	25	0.28 [0.16, 0.48]	7	0.012 [0.004, 0.033]
Old	21	0.23 [0.13, 0.42]	3	0.005 [<0.001, 0.024]
Total	57	0.63 [0.34, 1.17]	12	0.020 [<0.001, 0.080]
Other Signs				
Active	12	0.13 [0.06, 0.28]	0	0.000 [NE]
Recent	18	0.20 [0.11, 0.38]	2	0.003 [<0.001, 0.023]
Old	21	0.23 [0.13, 0.42]	2	0.003 [<0.001, 0.023]
Total	51	0.56 [0.30, 1.08]	4	0.006 [<0.001, 0.046]
Overall Total	254		40	
<u>White - Tailed Mongoose</u>				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	1	0.01 [<0.01, 0.12]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	1	0.002 [<0.001, 0.026]

Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Overall Total	2		1	
Honey Badger				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	0		0	
African Clawless Otter				
Direct Sighting	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Tracks				
Active	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
Total	1	0.01 [<0.01, 0.12]	1	0.002 [<0.001, 0.026]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Other Signs				
Active	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	2	0.02 [<0.01, 0.12]	0	0.000 [NE]

Overall Total	5		1	

Wild Primates and Prosimians

Lesser Galago				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	0		0	
Greater Galago				
Direct Sighting	0	0.00 [NE]	0	0.000 [NE]
Tracks				
Active	1	0.02 [<0.01, 0.12]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.02 [<0.01, 0.12]	0	0.000 [NE]
Spoor				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs				
Active	0	0.00 [NE]	0	0.000 [NE]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	0	0.00 [NE]	0	0.000 [NE]
Overall Total	1		0	
Baboon				
Direct Sighting	23	0.25 [0.14, 0.45]	37	0.061 [0.038, 0.097]

Tracks					
	Active	34	0.38 [0.23, 0.62]	30	0.049 [0.030, 0.083]
	Recent	2	0.02 [<0.01, 0.12]	2	0.003 [<0.001, 0.023]
	Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
	Total	37	0.40 [0.23, 0.87]	32	0.052 [0.030, 0.106]
Spoor					
	Active	0	0.00 [NE]	1	0.002 [<0.001, 0.026]
	Recent	0	0.00 [NE]	0	0.000 [NE]
	Old	0	0.00 [NE]	2	0.003 [<0.001, 0.026]
	Total	0	0.00 [NE]	3	0.005 [<0.001, 0.052]
Other Signs					
	Active	4	0.04 [0.01, 0.15]	0	0.000 [NE]
	Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
	Old	2	0.02 [<0.01, 0.12]	0	0.000 [NE]
	Total	7	0.07 [0.02, 0.40]	0	0.000 [NE]
	Overall Total	67		72	
<u>Vervet Monkey</u>					
Direct Sighting		0	0.00 [NE]	0	0.000 [NE]
Tracks					
	Active	0	0.00 [NE]	0	0.000 [NE]
	Recent	3	0.03 [0.01, 0.14]	0	0.000 [NE]
	Old	0	0.00 [NE]	0	0.000 [NE]
	Total	3	0.03 [0.01, 0.14]	0	0.000 [NE]
Spoor					
	Active	0	0.00 [NE]	0	0.000 [NE]
	Recent	0	0.00 [NE]	0	0.000 [NE]
	Old	0	0.00 [NE]	0	0.000 [NE]
	Total	0	0.00 [NE]	0	0.000 [NE]
Other Signs					
	Active	0	0.00 [NE]	0	0.000 [NE]
	Recent	0	0.00 [NE]	0	0.000 [NE]
	Old	0	0.00 [NE]	0	0.000 [NE]
	Total	0	0.00 [NE]	0	0.000 [NE]
	Overall Total	3		0	
<u>Blue Monkey</u>					
Direct Sighting		15	0.17 [0.08, 0.33]	0	0.000 [NE]
Tracks					
	Active	26	0.29 [0.17, 0.50]	3	0.005 [0.001, 0.024]
	Recent	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
	Old	0	0.00 [NE]	0	0.000 [NE]
	Total	27	0.30 [0.17, 0.62]	3	0.005 [0.001, 0.024]
Spoor					
	Active	3	0.03 [<0.01, 0.14]	1	0.002 [<0.001, 0.026]
	Recent	1	0.01 [<0.01, 0.12]	2	0.003 [<0.001, 0.023]
	Old	0	0.00 [NE]	0	0.000 [NE]
	Total	4	0.04 [0.01, 0.26]	3	0.005 [<0.001, 0.049]

Other Signs				
Active	7	0.08 [0.03, 0.20]	1	0.002 [<0.001, 0.026]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	1	0.01 [<0.01, 0.12]	0	0.000 [NE]
Total	8	0.09 [0.03, 0.32]	1	0.002 [<0.001, 0.026]
Overall Total	54		7	

CI: Confidence Interval. NE: Non-estimable.
N: Total number of camp radial surveys or transect survey segments completed. i: Camp radial survey or transect survey segment identity number. $\bar{n}_i$: Number of direct observations, tracks or signs detected per camp radial survey or transect survey segment. Active: Activity was directly observed or estimated to have occurred within the last 24 hours.
Recent: Activity estimated to have occurred between 2 and 5 days ago.
Old: Activity estimated to have occurred between 6 days and 6 months ago.

Appendix 2. Total and mean frequencies for each human activity observed per camp radial survey and per transect survey segment. Estimated means and 95% confidence interval for camp radial survey are based on best fit generalised linear mixed-effects model (GLMMs) with camp number and round number as random effects, assuming a negative binomial distribution, fitted using a penalised quasi-likelihood procedure with the *glmmPQL* package in R.

Activity	Camp Surveys (N = 76)		Transect Survey Segments (N = 616)	
	Total $\sum_{i=1}^{N} \bar{n}_i$	Mean [95% CI] $\bar{n}_\mathrm{i}$	Total $\sum_{i=1}^{N} \bar{n}_i$	Mean [95% CI] $\bar{n}_\mathrm{i}$
Livestock Herds of 10 or less [a]				
Active	65	0.52 [0.25, 1.03]	32	0.031 [0.014, 0.067]
Recent	22	0.18 [0.09, 0.38]	55	0.048 [0.026, 0.088]
Old	24	0.20 [0.10, 0.41]	31	0.033 [0.017, 0.064]
Total	111	0.90 [0.44, 1.82]	118	0.112 [0.057, 0.219]
Livestock Herding 11 or more [a]				
Active	181	1.55 [0.85, 2.82]	204	0.182 [0.107, 0.308]
Recent	69	0.62 [0.33, 1.15]	180	0.181 [0.107, 0.307]
Old	31	0.28 [0.14, 0.55]	95	0.100 [0.058, 0.175]
Total	281	2.44 [1.32, 4.52]	479	0.463 [0.272, 0.790]
Charcoal Burning [b]				
Active	82	0.70 [0.37, 1.33]	33	0.031 [0.016, 0.061]
Recent	77	0.63 [0.34, 1.91]	30	0.030 [0.015, 0.058]
Old	41	0.35 [0.18, 0.68]	27	0.026 [0.013, 0.052]
Total	200	1.68 [0.86, 3.20]	90	0.087 [0.044, 0.171]
Timber Harvesting [b]				
Active	6	0.06 [0.02, 0.16]	2	0.002 [<0.001, 0.011]
Recent	8	0.08 [0.03, 0.20]	1	0.001 [<0.001, 0.010]
Old	22	0.23 [0.11, 0.47]	3	0.003 [0.001, 0.013]
Total	36	0.37 [0.16, 0.82]	6	0.006 [0.001, 0.034]
Fishing [a]				
Active	16	0.14 [0.06, 0.30]	1	0.001 [<0.001, 0.010]
Recent	30	0.27 [0.14, 0.55]	3	0.003 [0.001, 0.013]
Old	14	0.14 [0.06, 0.30]	1	0.001 [<0.001, 0.010]
Total	60	0.54 [0.26, 1.15]	5	0.005 [0.001, 0.033]
Unauthorised Hunting [a]				
Active	0	0.00 [NE]	0	0.000 [NE]

Recent	1	0.01 [<0.01, 0.07]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	1	0.01 [<0.01, 0.07]	0	0.000 [NE]
Human Settlement [a]				
Less than 10 structures				
Active	108	0.84 [0.32, 1.01]	98	0.093 [0.053, 0.163]
Recent	9	0.08 [0.03, 0.12]	9	0.009 [0.004, 0.023]
Old	20	0.16 [0.08, 0.35]	11	0.012 [0.005 0.027]
Total	137	1.08 [0.43, 1.48]	118	0.114 [0.062, 0.213]
11 – 20 Structures				
Active	13	0.12 [0.05, 0.28]	22	0.022 [0.011, 0.045]
Recent	0	0.00 [NE]	1	0.001 [<0.001, 0.010]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	13	0.12 [0.05, 0.28]	23	0.023 [0.011, 0.065]
21 – 50 Structures				
Active	9	0.11 [0.04, 0.27]	15	0.019 [0.009, 0.040]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	9	0.11 [0.04, 0.27]	15	0.019 [0.009, 0.040]
≥ 51 Structures				
Active	4	0.03 [0.01, 0.11]	3	0.003 [0.001, 0.013]
Recent	0	0.00 [NE]	0	0.000 [NE]
Old	0	0.00 [NE]	0	0.000 [NE]
Total	4	0.03 [0.01, 0.11]	3	0.003 [0.001, 0.013]
Human-Dug Well [a]				
Active	43	0.34 [0.18, 0.67]	7	0.007 [0.003, 0.019]
Recent	16	0.13 [0.06, 0.29]	1	0.001 [<0.001 0.027]
Old	11	0.09 [0.04, 0.21]	7	0.007 [0.003, 0.020]
Total	70	0.57 [0.27, 1.17]	15	0.015 [0.006, 0.066]
Meat Poaching [a]				
Active	5	0.05 [0.02, 0.13]	1	0.001 [<0.001 0.010]
Recent	5	0.05 [0.02, 0.15]	1	0.001 [<0.001, 0.010]
Old	1	0.01 [<0.001 0.07]	0	0.000 [NE]
Total	11	0.11 [0.03, 0.36]	2	0.002 [<0.001, 0.020]

CI: Confidence Interval. NE: Non-estimable. N: Total number of camp radial surveys or transect survey segments completed. i: Camp radial survey or transect survey segment identity number. $\bar{n}_i$: Mean number of direct observations, tracks or signs detected per camp radial survey or transect survey segment.
[a] Active: Activity was directly observed or estimated to have occurred within the last 24 hours,

Recent: Activity estimated to have occurred between 2 and 5 days ago, Old: Activity estimated to have occurred between 6 days and 6 months ago.

[b] Active: Activity was directly observed or estimated to have occurred within the last month, Recent: Activity estimated to have occurred between 1 and 3 months ago, Old: Activity estimated to have occurred between 3 and 6 months ago.