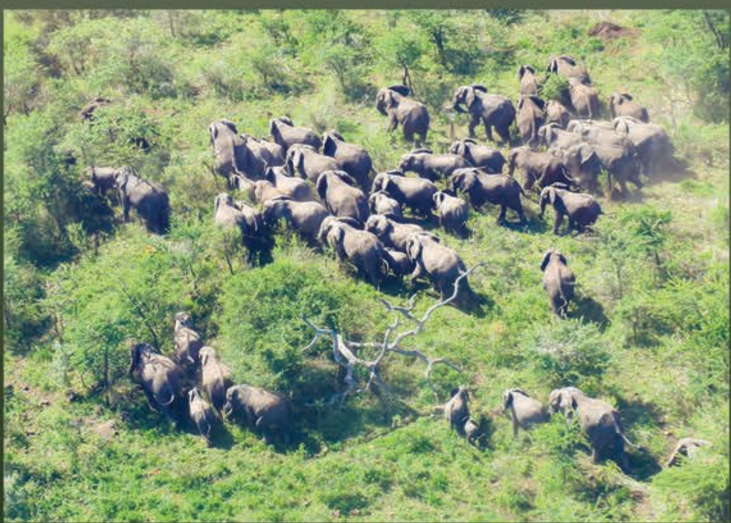
MINISTRY OF NATURAL RESOURCES AND TOURISM

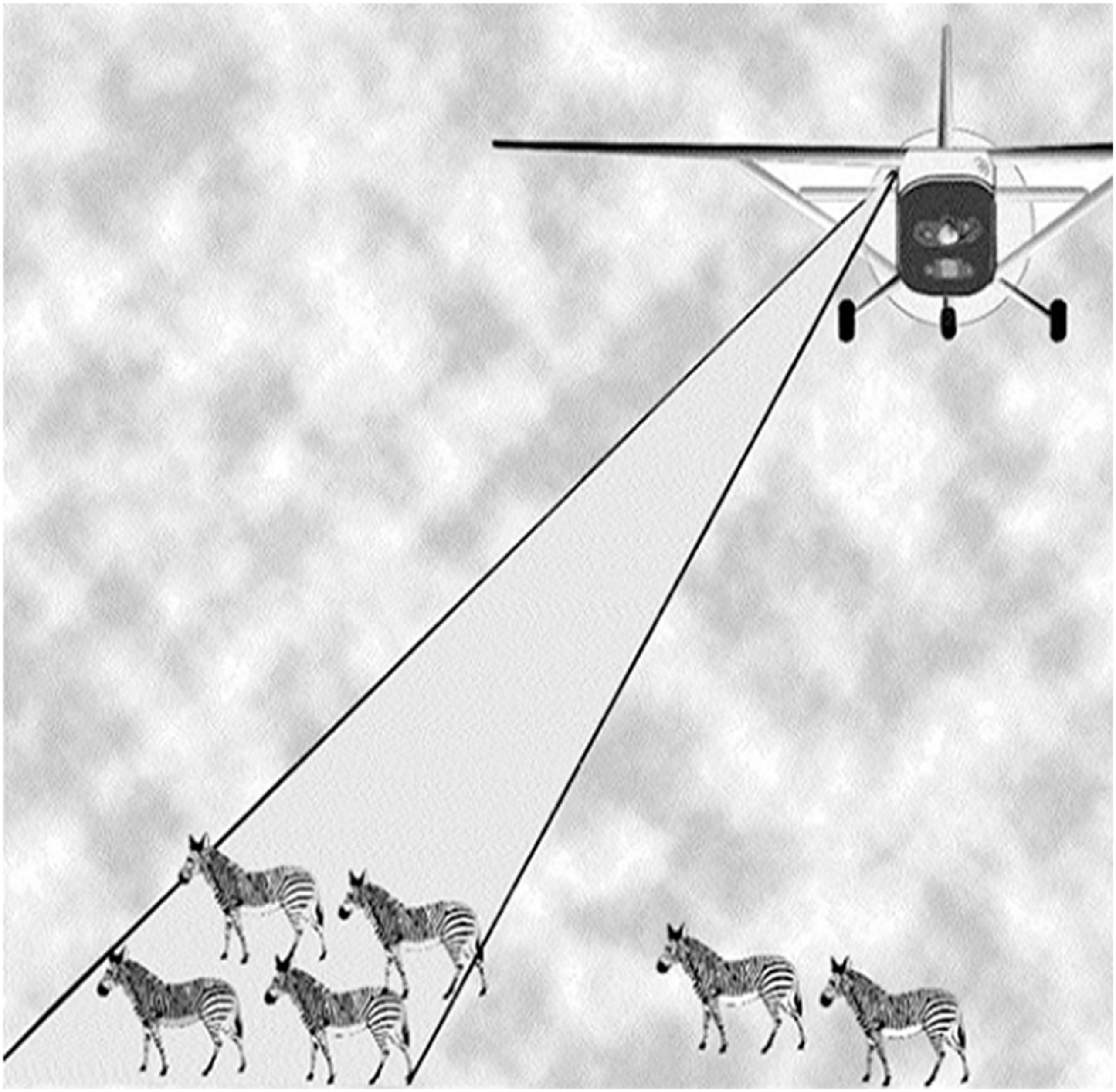
TANZANIA WILDLIFE RESEARCH INSTITUTE

AERIAL WILDLIFE SURVEY OF LARGE ANIMALS AND HUMAN ACTIVITIES IN NYERERE-SELOUS-MIKUMI ECOSYSTEM, DRY SEASON 2022



Systematic Reconnaissance Flight (SRF) Census Report

Aerial Census in the Nyerere-Selous-Mikumi Ecosystem, Dry Season 2022



Conducted by
TANZANIA WILDLIFE RESEARCH INSTITUTE

Editors

Alex Lobora
Eblate Mjingo
Stephen Nindi
John Bukombe
Hamza Kija
Devolent Mtui
Edward Kohi
Machoke Mwita
John Sanare
Howard Fredrick
Goodluck Massawe

Published by;
Tanzania Wildlife Research Institute,
P.O. Box 661,
Arusha, Tanzania.
Tel: +255 734 094646
Email: barua@tawiri.or.tz

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The successful implementation of the Nyerere-Selous-Mikumi ecosystem aerial survey was a product of thorough planning, hard work, and good collaboration between Government and Non-governmental partners led by the Tanzania Wildlife Research Institute. Other partners include;

TANZANIA NATIONAL PARKS
P.O. Box 3134, Arusha
email: info@tanzaniaparks.go.tz

Tanzania National Parks (TANAPA) was established in 1959 to manage and regulate the use of areas designated as National Parks.

TANZANIA WILDLIFE MANAGEMENT AUTHORITY
Dar-es-Salaam Road
Kingolwira Area
P.O.Box 2658, Morogoro
email: cc@tawa.go.tz

Tanzania Wildlife Management Authority (TAWA) was established by Ministerial order in 2014 to sustainably conserve and utilize wildlife resources in Game Reserves, Game Controlled Areas, and Open Areas.

FRANKFURT ZOOLOGICAL SOCIETY
P.O. Box 14935
Arusha, Tanzania
email: info@fzs.org

Frankfurt Zoological Society (FZS) is an international NGO working to conserve wildlife and ecosystems and has been present in Tanzania since 1959.

DEDICATION

This report is dedicated to Captain Bernard Shayo, who played a pivotal role in the successful execution of this census. Captain Shayo's unwavering commitment, exemplary piloting skills, and dedication to the conservation cause greatly contributed to the collection of valuable data during the survey.Unfortunately, before the report could be published, Captain Shayo was involved in a tragic plane crash at Matambwe airstrip whilst on a patrol mission in the Nyerere-Selous-Mikumi Ecosystem. His untimely departure is deeply mourned, and his immense contributions will be forever remembered and cherished. We extend our heartfelt condolences to Captain Shayo's family, friends, and colleagues. May his spirit and passion for wildlife conservation continue to inspire us as we work towards preserving Tanzania's natural heritage.

EXECUTIVE SUMMARY

This report presents the results of an aerial wildlife survey of large animals and human activities in the Nyerere-Selous-Mikumi Ecosystem in Southern Tanzania, covering a total area of 101,537 km². The survey was conducted from the 14th October to the 24th November 2022, with funding from the Government of Tanzania and the German Development Bank through the Frankfurt Zoological Society. The main objective of the census was to establish the population status of medium to large mammals, spatial distribution and human activities in the ecosystem. Compared to the previous census (2018), the current census revealed most species to remained stable, namely elephants from 15,501 ± 1,819 SE to 20,006 ± 1,793 SE, duiker from 11,021 ± 741 SE to 16,758± 963 SE, hippos from 31,086 ± 4,934 SE to 29,071 ± 4,146 SE, giraffes from 1,858 ± 461 SE to 1,679 ± 555 SE and wildebeest from 22,740 ± 3,330 SE to 19,060 ± 2,906 SE among others. On the other hand, some species have shown a downward trend, including impala from 19,296 ± 3124 SE to 14,031 ± 2,016 SE, puku from 1,579± 586 SE to 496± 186 SE, buffalo from 66,546± 11,470 SE to 59,878± 9,518 SE and kongoni from 23,250± 2,853 SE to 18,361 ± 1,853 SE.

Human activities are widespread in the ecosystem as evidenced by the presence of various indicators. For instance, the population of cattle and shoats has risen from 678,303 ± 73,205 SE to 799,411 ± 41,997 SE and 171,893 ± 27,304 SE to 179,330 ± 17,448 SE from 2018 to 2022 respectively. Similarly, sawpits have expanded from 9,015 ± 772 SE to 15,657 ± 4,633 SE, while huts with mabati roofs have grown from 13,611 ± 5,566 SE to 16,813 ± 2,558 SE. Regrettably, illegal activities were prevalent, including the occurrence of numerous sawpits and human habitation within Nyerere National Park. In general, though recent trends indicate stability for some species, the long-term trends indicate declining wildlife populations in this ecosystem, with puku, in particular, showing extreme range reduction and population decline.

Key findings:

- The results of the census indicate that most of the large mammal species in the ecosystem have maintained stable population compared to the previous census conducted in 2018. This stability can be attributed to significant management interventions aimed at curbing poaching and protecting these species, particularly elephants, buffalos, hippos, and wildebeests;
- In terms of elephant mortality, only one stage one and two-stage three carcasses were recorded in Nyerere National Park, while one stage three carcass was recorded in Mikumi National Park. These numbers represent a mortality rate of approximately 0.02%, which is below the normal threshold of eight percent. These findings highlight the success of conservation efforts in minimizing elephant poaching within the protected areas;
- The puku population, however, experienced a dramatic decline compared to previous years calling for urgent attention and concerted efforts to protect and conserve this species;
- The census results also reveal an extended existence of human activities within the ecosystem, including an increase in cattle, shoats (sheep and goats), donkeys, cultivation, human settlements, and sawpits. These human activities pose significant threats to wildlife conservation as they can result in habitat loss, fragmentation, and disturbance. The findings emphasize the need for effective management and control measures to mitigate the negative impacts of human encroachment on the ecosystem; and
- Overall, while the stable populations of large mammal species and low elephant mortality rates indicate successful conservation efforts, the decline in the puku population and the escalation of human activities within the ecosystem pose ongoing challenges. It is imperative to continue implementing proactive management strategies and conservation measures to safeguard the biodiversity and ecological integrity of the ecosystem.

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ABBREVIATIONS AND ACRONYMS

CIMS	Conservation Information and Monitoring Section
CIMU	Conservation Information and Monitoring Unit
CITES	Convention on International Trade in Endangered Species
FSO	Front Seat Observer
FZS	Frankfurt Zoological Society
GCA	Game Controlled Area
GPS	Global Positioning System
GR	Game Reserve
IUCN	International Union for Conservation of Nature
JUKUMU	Jumuiya ya Kuhifadhi na Matumizi Bora ya Maliasili UKUTU
KfW	German Development Bank (Kreditanstalt für Wiederaufbau)
MIKE	Monitoring the Illegal Killing of Elephants
NALIKA	Namwinyi, Ligunga and Kalulu
NP	National Park
NR	Nature Reserve
NSME	Nyerere-Selous-Mikumi Ecosystem
OAs	Open Areas
PA	Protected Area
QGIS	Quantum Geographical Information Sytem
RSO	Rear Seat Observer
SE	Standard Error
SGR	Selous Game Reserve
SRF	Systematic Reconnaissance Flight
TANAPA	Tanzania National Parks
TAWIRI	Tanzania Wildlife Research Institute
TWCM	Tanzania Wildlife Conservation Monitoring
UNESCO	United Nations Education, Scientific and Cultural Organization
URT	United Republic of Tanzania
WMA	Wildlife Management Areas

GLOSSARY OF TERMS

Survey Area (Z)
The whole area in which the number of animals is to be estimated. In some censuses, the survey area is divided into sub-zones (strata) for various reasons. For example, divisions could be based on political and/or management boundaries or ecological zones.

Sample zone
That portion of the survey area searched and counted. Counting every animal in a protected area would be prohibitively expensive and time-consuming (sizes ranging from 200 to 150,000 km^2). For this reason, only parts of the survey area are searched and assume that what is seen in those parts (samples) represents what we would be if we searched over the other parts. In SRF, the sample zone is made up of transects and each transect represents a sample unit.

Population Estimate (Y)
All animal and human activities recorded during an SRF. The assumption made is that animals are evenly distributed over the survey area so that if 10% of the area is searched, it will contain about 10% of the animals. This allows the estimation of the number of animals in the survey area. *The standard error* describes how exact (reliable) our population estimate is.

Standard Error (SE)
Because animals are less likely to be evenly distributed over the census zone, each transect/sample will vary in the density of animals it contains. Therefore, any single population estimate may be higher or lower than the true population total. The potential magnitude of this sampling error can be determined by examining the variation between the number of animals counted in each sample unit; hence, the standard error measures this variation. If the standard error is small, we can estimate the population within a narrow range of numbers (we say the estimate is precise). If the standard error is high, the true population estimate lies within a wide range of possible numbers. **Caution must be taken when interpreting estimates with wide standard errors** (above 20% of the estimate), as the wider the SE, the less reliability should be put on the estimate. Critical management decisions should not be based on a single SRF estimate with *wide standard errors.*

Confidence Limits (Cl)
The population sizes in our reports are estimates (see "Population estimate" above); therefore, knowing the lowest and highest probable population size is helpful. Confidence limits are a way of describing these upper and lower bounds on our estimate. By default, the confidence limits presented in our reports are "95% confidence limits"; that is, there is a 95% probability that the true population size falls within these limits

Significant difference (d- test between population estimates)
It is often required to compare two or more population estimates for a given species, to conclude whether the species is increasing or decreasing in numbers. Estimates from two surveys may differ due to sample variation or a true change in population size. Two estimates significantly differ at the 5% level if the d value exceeds 1.96. A significant difference between population estimates strongly suggests that the population has increased or decreased between surveys. If the difference is insignificant, then we do not have any statistical evidence for population change; in effect, we must assume the population has stayed the same.

1. INTRODUCTION

Wildlife surveys provide valuable information about wildlife populations, such as how many they are, how they are distributed and what drives their changes over time. Aerial surveys are particularly useful for rapidly covering large areas, mapping the distribution of animals and livestock as well as human activities, including livestock and cultivation in areas of interest. Routine aerial surveys of some protected areas in Tanzania have been conducted since 1958 and provided one of the most important ecological datasets in the world, allowing wildlife managers to manage populations and explain population trends and events such as the wildebeest migration. In Tanzania, aerial wildlife surveys are conducted in major ecosystems covering around 300,000 km² on a roughly three-year cycle. Regular surveys in these ecosystems allow managers to monitor wildlife population trends, spatial distributions and detect problems such as poaching, habitat loss, and human disturbance. The maps are particularly useful in understanding where natural resources are located and what is affecting them, providing a foundation for effective conservation (Goodchild *et al.*,1992; Ahmad & Pande, 2019).

The Nyerere-Selous-Mikumi Ecosystem (NSME) is one of Tanzania's major ecosystems and Africa's largest remaining wilderness and big game populations, with an area of approximately 101,537km². Historically, NSME contained globally significant populations of African elephants (*Loxodonta africana*), but the population has declined during the last decades due to an increase in poaching and the rapidly growing human populations, which consequently decreased the space available to elephants and the connectivity between protected areas (Kideghesho, 2016; Ntukey *et al*., 2022). Additionally, the ecosystem is one of the world's strongholds for wild dogs (*Lycaon pictus*) the world's largest populations of hippopotamus (*Hippopotamus amphibius*) and cape buffalo in Africa (World Heritage Committee, 2010; UNEP-WCMC, 2011). It also hosts one of only two populations of puku (*Kobus vardonii*) in Tanzania. Because of its outstanding importance of high biodiversity and natural habitat for the conservation of biological diversity, the government, through the Tanzania Wildlife Research Institute (TAWIRI), has been undertaking regular wildlife aerial surveys in NSME to determine abundance and spatial distribution of wildlife and human activities within and adjacent areas.

TAWIRI, in collaboration with other wildlife stakeholders, namely, Tanzania Wildlife Management Authority (TAWA), Tanzania National Parks (TANAPA), and Frankfurt Zoological Society (FZS), with funds from German Development Bank (KfW) through Frankfurt Zoological Society (FZS) conducted a routine aerial wildlife census in NSME during the dry season from the 14th October to 24th November 2022. The census aimed to establish the population status, trends and spatial distribution of medium to large animals. The census also aimed to assess human activities current status and distribution in the ecosystem. So far, 16 surveys have been carried out in this ecosystem and the survey area has increased from 73,959 km² in the 1970s to 101,537 km² in 2022 (Appendix 3).

2. SURVEY AREA AND METHODS

2.1. Survey area

The Nyerere-Selous–Mikumi Ecosystem is one of the largest faunal reserves in the world located in southern Tanzania between latitude -6.798° and -11.798°S and longitude 37.282° to 36.567°E and latitude -9.361° to -9.475°S and longitude 35.544° to 39.351°E. The ecosystem covers an area of approximately 101,537km², roughly more than the size of Rwanda, Zanzibar, Switzerland and Burundi combined. It comprises various administrative areas: Nyerere and Mikumi National Parks, Selous, Lukwika-Lumesule and Liparamba Game Reserves, Mwambesi Nature Reserve, Kilombero Game Controlled Area (now Kilombero Game Reserve), Gezamasua Forest Reserve, and Selous-Niassa wildlife corridor. Other conservation areas include the Wildlife Management Areas of Chingolie, ILUMA, JUKUMU, Kisungule, Kimbanda, Mbarang'andu, NALIKA-Tunduru, Ngarambe-Tapika, Liwale, and adjacent Open Areas (OAs). The Nyerere-Selous-Mikumi is a cross-border area linking Tanzania and the northern part of Mozambique (Figs 1&2).

The ecosystem has been a UNESCO World Heritage Site since 1982 due to the diversity of its wildlife and undisturbed nature. It has exceptionally high value for biodiversity and conservation, including the presence of wildlife species such as hartebeest, African buffalo, Niassa wildebeest, eland, greater kudu, common waterbuck, bushbuck, common reedbuck, zebra, impala and klipspringer, African wild dog, lion and leopard and spotted hyaena (UNESCO & IUCN, 2013). The wildlife's spatial distribution and occurrence vary substantially depending on the seasonality in the ecosystem. The ecosystem has an exceptional mosaic of vegetation types, including mixed Miombo (Brachystegia spp), primarily comprised of mixed woodlands and grassy woodlands dominated by Acacia spp, Julbernardia spp. and Isoberlinia spp., wooded grasslands, open savannahs, granite inselbergs, wetlands and riverine forests along numerous accounts for globally significant biodiversity. The permanent water sources in the ecosystem are the Mbarangandu, Lukimwa, Msangesi and Sasawala, Rufiji, Kilombero, Luwegu and Ruvuma rivers. The Great Rufiji, Ulanga and Matandu rivers make the ecosystem have such a diverse landscape for both boating safaris and sport fishing.

The ecosystem has a dry sub-humid climate influenced by the prevailing southeasterly winds, bringing rainfall to the eastern arc mountains. The annual precipitation ranges from 750mm in the east to 1,300mm in the west, falling mainly between mid-November and mid-May but is variable. The yearly average range of maximum and minimum temperatures at Kingupira on the hotter eastern edge is between 17.9°C and 37.3°C but for the whole ecosystem range from 13°C to 41°C, depending on elevation. The six months of the cold season are very dry.

The ecosystem has numerous permanent and seasonal water bodies, notably the Rufiji River (the largest river in East Africa) with its tributary, the Ruaha River, which drains a large part of southern and central Tanzania. The Rufiji River is formed where the Ruaha and Ulanga Rivers join above the Shughuli Falls. In the southwest, the two PAs are drained by Kilombero, Luhombero, Mbarang'andu and Njenje Rivers which are the main permanent rivers and several other lakes and swamps (Michael *et al*., 2016). The Matandu River drains the southeast border of the ecosystem below the Rufiji-Ruaha confluence and the northern border of the two PAs is drained by the Mgeta River. In the southern part of the ecosystem is the Ruvuma River, which forms the international boundary between Tanzania and Mozambique and constitutes a significant part of the ecosystem.

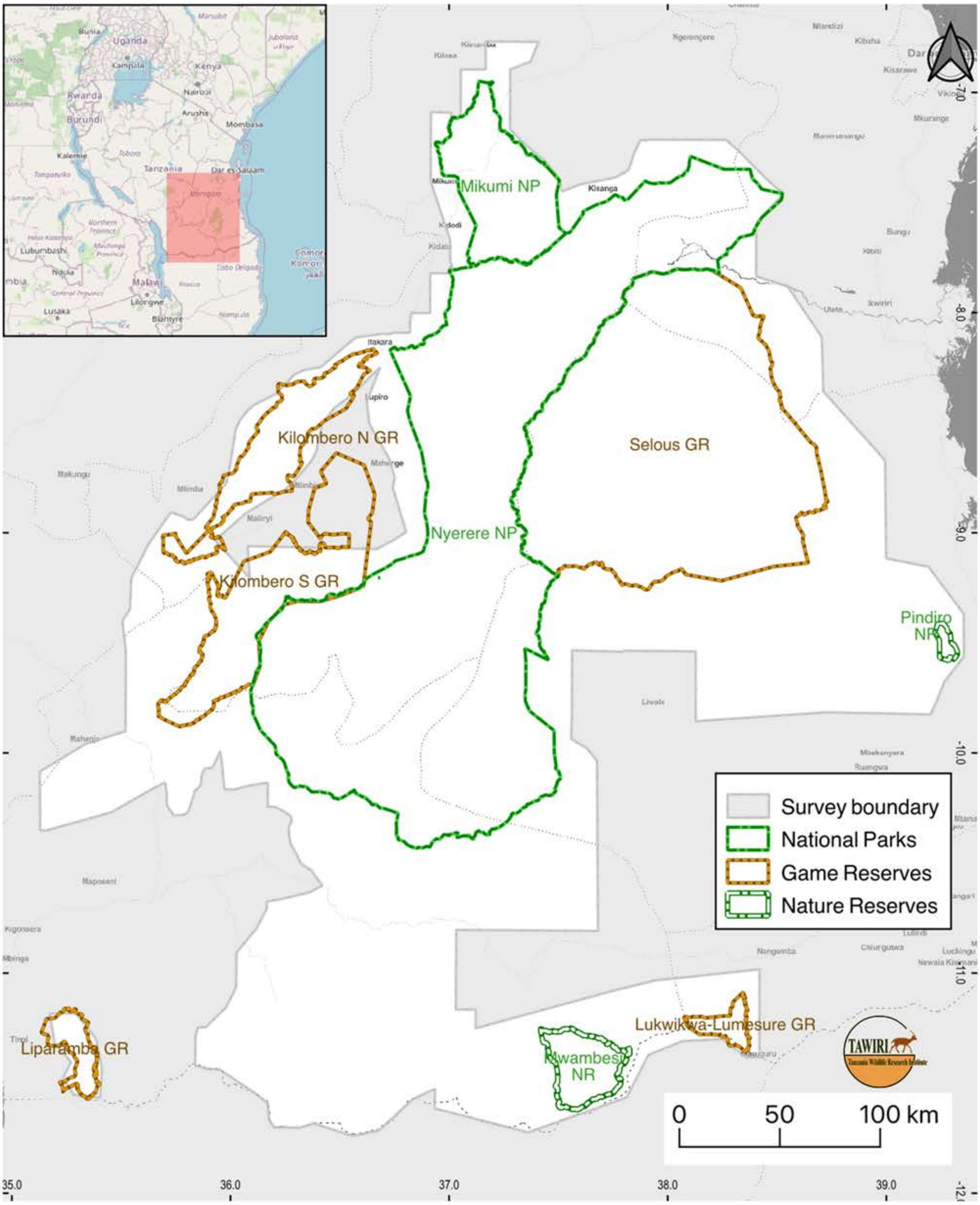


Figure 1: Boundaries of administrative areas in the ecosystem

The Ruvuma river stretches some 730 km from its source to the Indian Ocean and drains an area of approximately 155,400 sq. km. The river, tributaries and associated catchments are hotspots for biodiversity conservation. Large wetlands, lowland coastal forests and mangroves are some of the habitats occurring along the river. The Mikumi National Park is primarily drained by the Mkata River and its flood plain is perhaps the most reliable place in Tanzania for sightings of the powerful eland, the world's largest antelope. The park is also ushered by several isolated islets and Hippo pools.

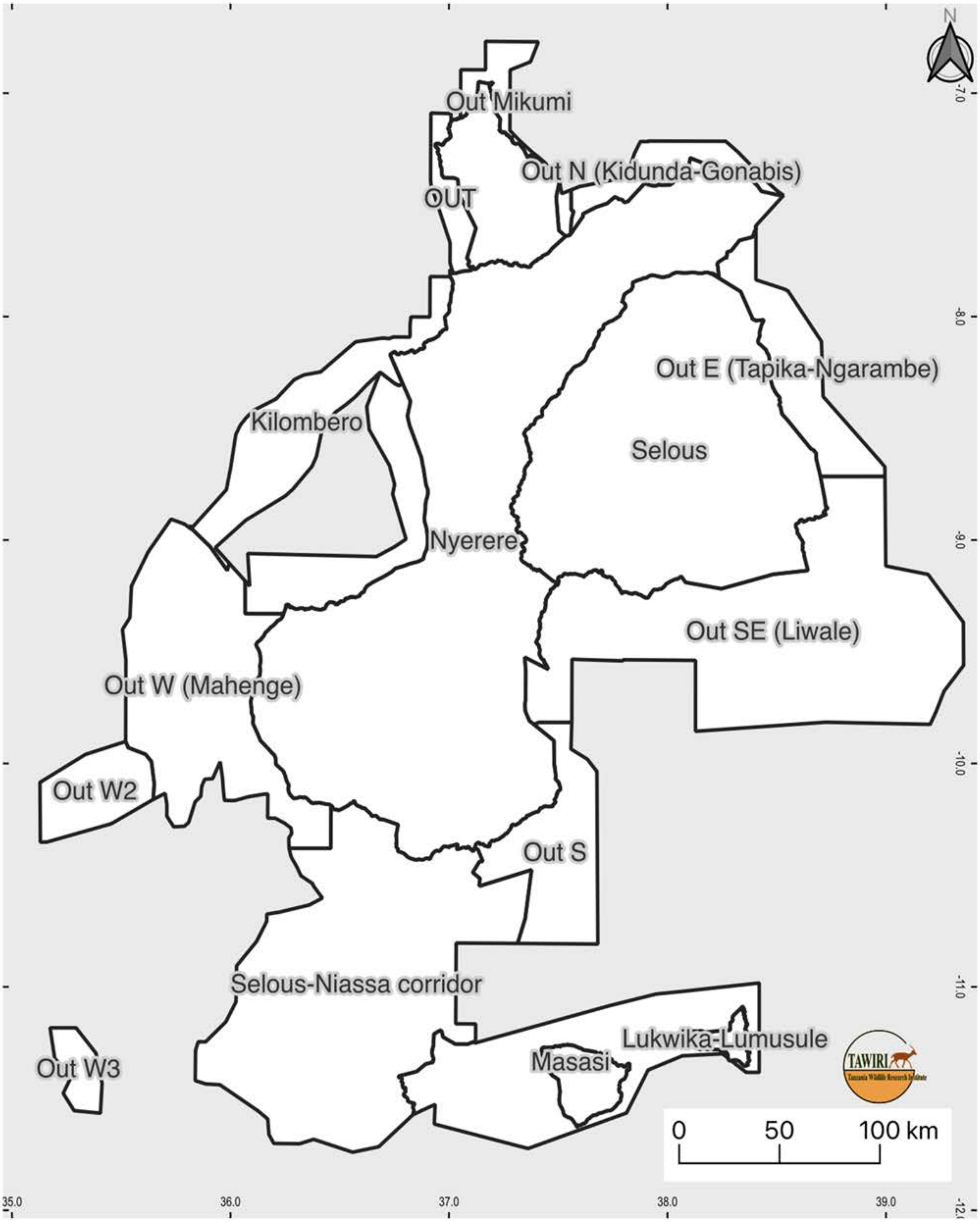


Figure 2: Survey strata in the ecosystem

2.2. Methods

2.2.1. Training

Prior to fieldwork, the core census team at TAWIRI i) selected crews with experience in wildlife census from within the wildlife sector, including knowledge in flying with small aircraft and wildlife species identifications, ii) tested the crew on visual acuity and colour blindness before the start of the exercise by using approved test kits, iii) calibrated and familiarised flying crew with equipment use and flying endurance for at least two sessions of 4:30 hours for experienced observers and three sessions of 5 hours for new observers after training, iv) trained crew on how to take photographs of all groups and carcasses of elephants, and all animal groups with more than ten individuals and v) trained all crew members in counting animals in the photographs to ensure easy recall of data during the actual exercise.

2.2.2. Transect design and flight plan

Using QGIS 3.6, the core team generated survey transects spaced at 2.5 km, 5 km, and 10 km intervals, with transect orientation varying due to the nature of the terrain and ecological gradient to maximise the number of samples (Fig. 3). Transects were a priori evenly subdivided into subunits with a distance of no more than 2.5 km in length (typically 40 seconds of flying time) and uploaded onto GPS units. The on-transect navigation was maintained using handheld GPS (Garmin 62S, 64S, 65S) and 695 models mounted to the aircraft to assist the pilot in transect navigation and radar or laser altimeter (Lightware SF30-D Laser Rangefinder). The total planned transect flight time ranged from a minimum of 5 to a maximum of 30 minutes and counting sessions (on transect time) did not exceed 4 hours from start to finish, with most being less than or equal to 3 hours and 30 minutes.

2.2.3. Data collection techniques

This census primarily employed Systematic Reconnaissance Flight (SRF) technique described in detail by Norton-Griffiths (Norton-Griffiths, 1978). The method is widely used to evaluate the distribution and abundance of wild animals across Africa, Australia, and North America. The technique involves flying systematic transects over the target area consistently above ground. At least one observer records wildlife in a calibrated strip on at least one side of the aircraft. Despite a few criticisms pertaining to low precision, SRF is still regarded as the best method for relatively inexpensive coverage of large areas, open habitats, and larger animals but provides poor results for smaller or more cryptic animals and some human activities.

Reconnaissance flights (Fig. 3), which involve flying a grid over an area and recording all observations, was also employed in small pockets of the survey areas where SRF was unsafe due to the highly rugged terrain, including the southern part of Mikumi National Park and western part of Nyerere National Park, especially in Mahenge mountain and southern part of Kilombero GCA (recently upgraded to Kilombero Game Reserve). Three Cessna (182) and one 206 aircraft (Table 1) were used, each flying at a target height of 350 ft (about 100 m) above ground and a target speed of 175 km/h.

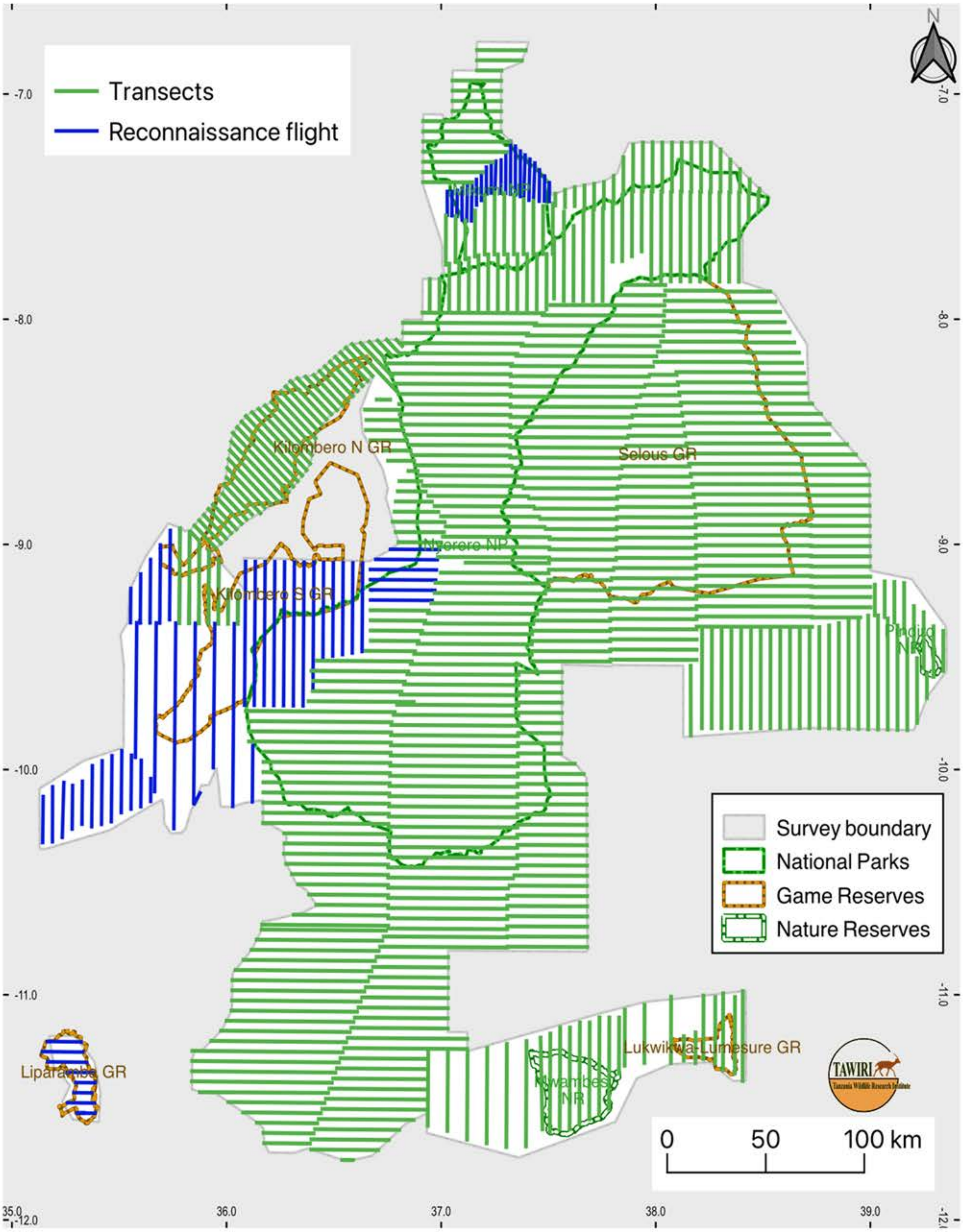


Figure 3: Transect and reconnaissance design for the 2022 dry season aerial survey in the ecosystem

2.2.4 Data collection

During the survey, each aircraft was manned by a crew of four. The pilot was responsible for navigating the aircraft according to a predetermined survey plan uploaded onto the GPS prior to the flight. The Front Seat Observers (FSO) were tasked with recording metadata related to each transect, such as its start and end points, flight height above ground using a radar or laser altimeter in each subunit, and the presence or absence of water and burnt areas. The FSO also communicated subunit identification numbers to the Rear Seat Observers (RSO). The RSOs were responsible for counting and recording all sightings of wild animals and human activities observed in each sub-unit along the transect. Large groups of more than ten individuals were photographed during the survey for verification purposes. After each flight session, the RSOs transcribed recorded data onto data sheets. The geographical position of each subunit, called out by the FSO, was recorded along with its observations and later transcribed onto data sheets. Streamers attached to the wing strut on each side of the aircraft defined the sample area for counting, with a target width of 150m on the ground. This target width was calibrated before the census and with supplementary data collected regularly to ensure consistency.

Recorded elephant carcasses were categorised using guidelines recommended by the MIKE-CITES program (Griffin *et al.*, 2003). These guidelines outlined specific characteristics used to assign carcass classes (1-4) and approximate ages since the animal's death. The first class, carcass stage 1 (EC1), described a carcass less than one-month-old with flesh, a rounded appearance, and frequently with vulture’s present. The ground may still be moist from body fluids. The second class, carcass 2 (EC2), typically referred to carcasses less than one-year-old with rot patches and skin still intact and with the skeleton not scattered. Carcass 3 (EC3), the third class, usually indicated carcasses older than one year with white bones, absent skin, and vegetation regrowth in rot patches. The fourth and final class, carcass IV (EC4), described very old carcasses up to 10 years. It is important to note that the first three classes (in strip) were used in calculating the mortality rates of elephants in this census report.

2.2.5 Census parameters and track-log

During the actual census, animal species observed within transects, flight height and speed were recorded to provide an understanding of how well the survey crews were performing and an indication of the count's accuracy. In addition, survey standards for flight parameters were evaluated during training and at regular intervals during the count. Important quantitative parameters such as aircraft speed, altitude, flying height above ground and heading obtained from GPS track log data were mapped and reviewed with survey crews to ensure that survey standards were being met (Table 1).

Table 1: Basic SRF census parameters employed during the survey in 2022

Parameters		5H-FZS	5H-SGR	5H-SNP	5H-TPK	COMBINED
Survey area (km^2)		41,709	20,425	29,417	9,997	101,537
Sample Areas (km^2)		2,249	1,222	1,696	600	5,768
Transect distance		8,276	4,083	5,916	1,999	20,274
Total number of transects		168	122	162	53	505
Total number of subunits		3,386	1,688	2,441	824	8,339
Sample Fraction %		5.4	6.0	5.8	6.0	5.7
Flying height:						+
Mean		313	353	357	357	338
Standard Deviation		47	13	41	33	44
	Lower 10%	255	341	324	337	
	Upper 10%	360	368	390	384	
Strip width						
	Left	134	151	147	152	
	Right	138	148	140	148	
	Total	272	299	287	300	
Average Ground speed (km/h)		158	161	165	166	

The total area covered by the four aircraft was 101,537 km² flying through 465 transects (Fig. 3). The mean height above ground for all aircraft was 338 feet and ground speed averaged 162 km/h (Table 2). Transect strip widths were between 134 and 152 m, as one aircraft maintained a low flying height and thus smaller strip widths (134 and 138m) (Table 2). Flight parameters were reviewed using Mapsource software version 6.1.6, tracklogs from pilot and FSO GPS were downloaded, and QGIS 3.6 was used for mapping (Fig.4).

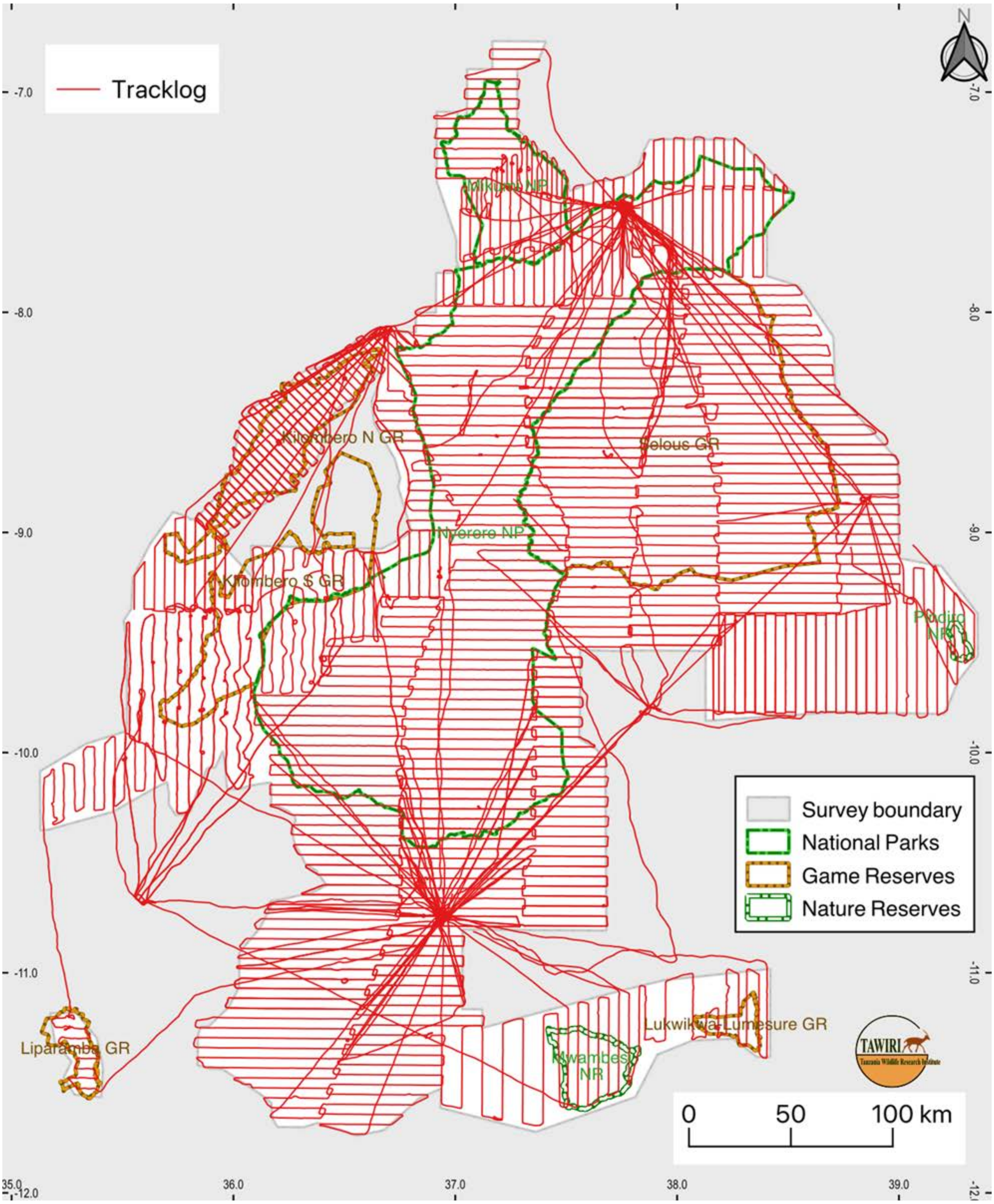


Figure 4: Track log of flights in the ecosystem during the survey in 2022

2.2.6. Data Analysis

Data collation from all transects flown and the subsequent cleaning and validation was done using Microsoft Excel and later exported to R statistics for analyses. Using Jolly's unequal sample size method 2 (Jolly, 1969; Norton-Griffith, 1978), R-scripts, population estimates and d-test were then generated in R Statistics 4.2.1. However, it is worth noting that, at a minimum, 30 observations per species are required to qualify the required sample size for generating meaningful results. For each estimate, the "Standard Error" shows the range of estimated values we would most likely get if the survey was repeated. This range is often wide for species with low numbers, or which are highly aggregated, indicating that we are unsure of the exact estimate.

After generating estimates and their variance, d-test was used to test the current and previous population estimates to determine whether the species is increasing or decreasing in numbers and whether these changes are significant (Cochran, 1954). Estimates from two surveys may differ due to sample variation or a true change in population size. Two estimates are significantly different at the 5% level if the d value exceeds 1.96. A significant difference between population estimates strongly suggests that the population has increased or decreased between surveys. If the difference is insignificant, then we do not have any statistical evidence for population change; and must assume the population has stayed the same.

To determine wildlife population trend in the ecosystem, current estimates were compared to previous estimates (relative to census area) to show trends over time. These estimates are presented as two figures, the likely population size +/- the statistical variation expressed as standard error (SE). The standard error indicates confidence in the estimate – indicating that if the survey were repeated, the new estimate would be within the range of the estimate plus or minus the SE value. They are presented as totals for the survey area and subdivided by administrative blocks/areas. Clean datasets were subjected to QGIS 3.6 to obtain spatial wildlife distributions and human activities and presented in maps showing i) density, indicated by shades of colours which are darker where higher concentrations were recorded and ii) point observations (dots) indicating locations where observations were made. A d-test was used to determine whether the current and previous estimates differed significantly.

Additionally, Species densities, distribution, and human activities were mapped using QGIS 3.6. Finally carcass ratio, an index used to ascertain whether mortality in the elephant population is unnaturally high (Douglas Hamilton & Burrill, 1991) was calculated. This ratio was calculated from the proportion of dead to live+dead elephants using the following formula:

$$\text{Carcass ratio:} \quad \frac{c}{(E + c)} * 100$$

c is for the number of carcasses counted; E is the number of live elephants counted

3. RESULTS AND DISCUSSION

3.1 Wildlife Estimates

A total of twenty-two (22) medium to large mammal species and one avian species were recorded in the survey area (Table 2). The most abundant species was buffalo (59,878 ± 9,518 SE), followed by hippo (29,071 ± 4,146 SE), elephant (20,006 ± 1,793 SE), wildebeest (19,060 ± 2,906 SE), kongoni/hartebeest (18,361 ± 1,853 SE), duiker (16,758 ± 963 SE) and zebra (16,669 ± 1,828 SE). On the other hand, the least two abundant species were bushbuck (1,227 ± 305 SE) and puku (496± 186 SE). Other species were also observed, but either SRF is not an appropriate method for them (Table 2).

Table 2: Wildlife and elephant carcass estimate in the ecosystem in 2022

SN	Wildlife	Field count	Estimate	SE	Recce	Total
1	Buffalo	3,309	**58,239**	9,518	1,639	**59,878**
2	Hippo	1,640	**29,056**	4,146	15	**29,071**
3	Elephant	1,131	**19,921**	1,793	85	**20,006**
4	Wildebeest	1,094	**19,060**	2,906	-	**19,060**
5	Kongoni/Hartebeest	1,035	**18,361**	1,853	-	**18,361**
6	Duiker	931	**16,745**	963	13	**16,758**
7	Zebra	951	**16,667**	1,828	2	**16,669**
8	Impala	798	**13,988**	2,016	43	**14,031**
9	Warthog	782	**13,803**	1,475	3	**13,806**
10	Sable Antelope	508	**8,991**	1,379	17	**9,008**
11	Ground Hornbill**	352	**N/A**	N/A	7	**N/A**
12	Waterbuck	349	**6,138**	897	18	**6,156**
13	Eland	277	**4,852**	1,256	50	**4,902**
14	Baboon**	201	**N/A**	N/A	12	**N/A**
15	Reedbuck	126	**2,197**	541	-	**2,197**
16	Wild Pig**	100	**N/A**	N/A	-	**N/A**
17	Giraffe	96	**1,677**	555	2	**1,679**
18	Greater Kudu	80	**1,414**	333	-	**1,414**
19	Crocodile**	72	**N/A**	N/A	-	**N/A**
20	Bushbuck	70	**1,227**	305	-	**1,227**
21	Puku	38	**496**	186	-	**496**
22	Hyaena	8	**N/A**	N/A	N/A	**N/A**
23	Elephant bones - grey	6	**N/A**	N/A	N/A	**N/A**
24	Elephant bones - white	3	**N/A**	N/A	N/A	**N/A**

**Method inappropriate

3.2 Wildlife population trend

Results on wildlife trends showed that, of the 18-mammal species tested, 16 indicated stable population trends (Table 3). Duiker is the only species which showed increasing population trends in the Nyerere-Selous-Mikumi ecosystem (d-test >1.96). However, it is important to note that trend analyses can be useful for drawing attention to population changes but are not accurate for species with very low populations or which have high concentrations in some areas (which leads to high statistical variation). Trend graphs showing patterns over several surveys are often more meaningful.

3.2.1 Species with a declining trend

None of the tested species showed a significant declining trend compared to 2018 estimates (Table 3). However, it is important to note that puku was already very low in 2018 and as noted above, the statistics are less useful for a species already low in number. Though it shows a near-significant decline (d =-1.46, $p < 0.15$), the trend graph (Fig. 33) clearly reveal a continuing long-term decline and there are less than one half the puku remaining compared to 2018. Their range is apparently strongly affected by human activities in the Kilombero area (Figs. 41,42,43,44).

3.2.2 Species with increasing trend

All duiker species observed (combined) were estimated at a population of 16,758 ± 963 SE (Table 2). Noting the fact that duikers are difficult to see from the aircraft and may be confused with other small antelopes such as dik-dik, suni or sharpe's grysbok, the estimates presented may probably involve slight underestimates or possibly little overestimated values. Warthog, which were estimated at a population of 13,806 ± 1,475 SE across the study ecosystem, has increased with time, based on past surveys. Though both species are smaller and subject to underestimation from the aircraft, these increasing trends bear further investigation as they may represent changes in habitat at the same time as we have seen long-term declines in other larger species.

3.2.3 Species with stable population trends

Apart from duiker which exhibited a significant increase over the past four years, most other wildlife species exhibited stable populations when compared to the 2018 census (Table 3).

Table 3: Wildlife population trends in the ecosystem between 2018 and 2022

Year Area Species Name	2018 105,730 km² Estimate	SE	2022 101,537 km² Estimate	SE	d-test
Elephant	15,501	1,819	20,006	1,793	1.76
Elephant carcasses (total)	2,966	559	158	51	-5
Buffalo	66,546	11,470	59,878	9,518	-0.48
Hippo	31,086	4,934	29,071	4,146	-0.26
Puku	1,579	586	496	186	-1.59
Impala	19,296	3,124	14,031	2,016	-1.43
Zebra	22,690	2,698	16,669	1,828	-1.85
Duiker**	11,021	741	16,758	963	4.72
Eland	5,541	2,061	4,902	1,256	-0.29
Giraffe	1,858	461	1,679	555	-0.25
Kudu	3,053	1,215	1,414	333	-1.18
Kongoni	23,250	2,853	18,361	1,853	-1.43
Sable	5,921	1,201	9,008	1,379	1.68
Warthog	17,475	1,469	13,806	1,475	-1.76
Waterbuck	4,049	850	6,156	897	1.69
Wildebeest	22,740	3,330	19,060	2,906	-0.83
Baboon	1,584	440	3,537	958	1.84
Crocodile	348	127	1,277	536	1.69
Reedbuck	4,223	1,454	2,197	541	-1.31

** Significant increase

3.3.1 Buffalo estimates, distribution and density

Buffalo was the most abundant species in the survey area (59,878 ± 9,518 SE) (Table 2). Administratively, Nyerere NP had more (34,950 ± 8,116 SE), followed by Selous GR (14,914 ± 3,255 SE), Mikumi NP (3,814 ± 3,093 SE) and Selous-Niassa Corridor (1,882 ± 1,495 SE) (Appendix 4). Generally, buffalo population remained stable from 2018 to 2022, however, the overall trend from 2002 shows a major decline in the population (Fig. 6).

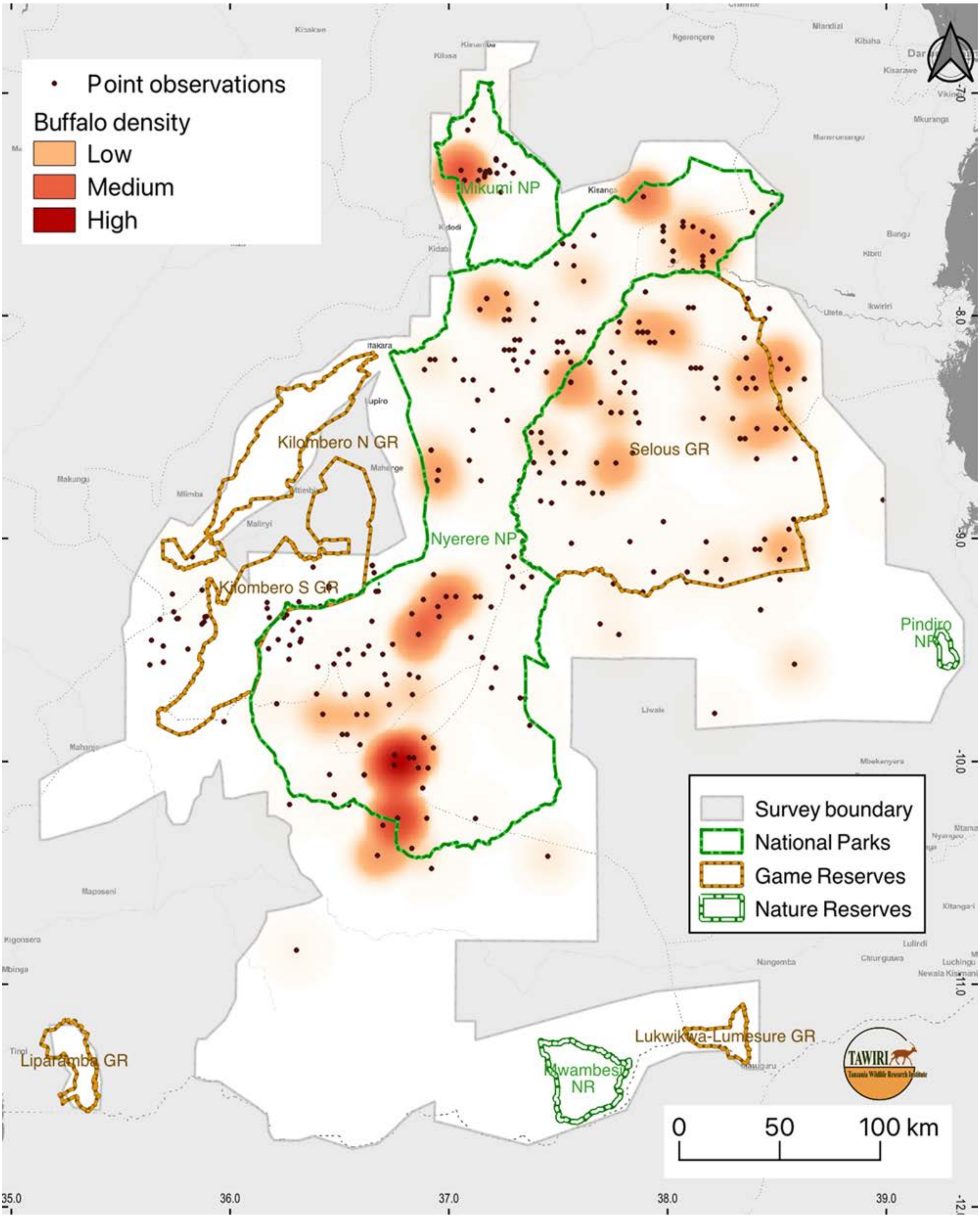


Figure 5: Dry season buffalo distribution and density in the ecosystem in 2022

During the survey, no buffalo were observed in Kilombero GCA, Masasi, Outside Mikumi, Mikumi west, Outside in Kidunda and Gonabis, Mbalika, Lukwika-Lumesule, and Mwambesi NR. In Nyerere NP, buffalo were randomly distributed across the entire park, whereas in Selous GR, they were highly concentrated in the southeast part, southwest, northwest and few in the north-eastern part. In Mikumi NP, buffalo were widely distributed in the north and central parts, and very few observations were in the southern part. In the Selous-Niassa, high concentration was observed in the central-northern part (Fig. 5).

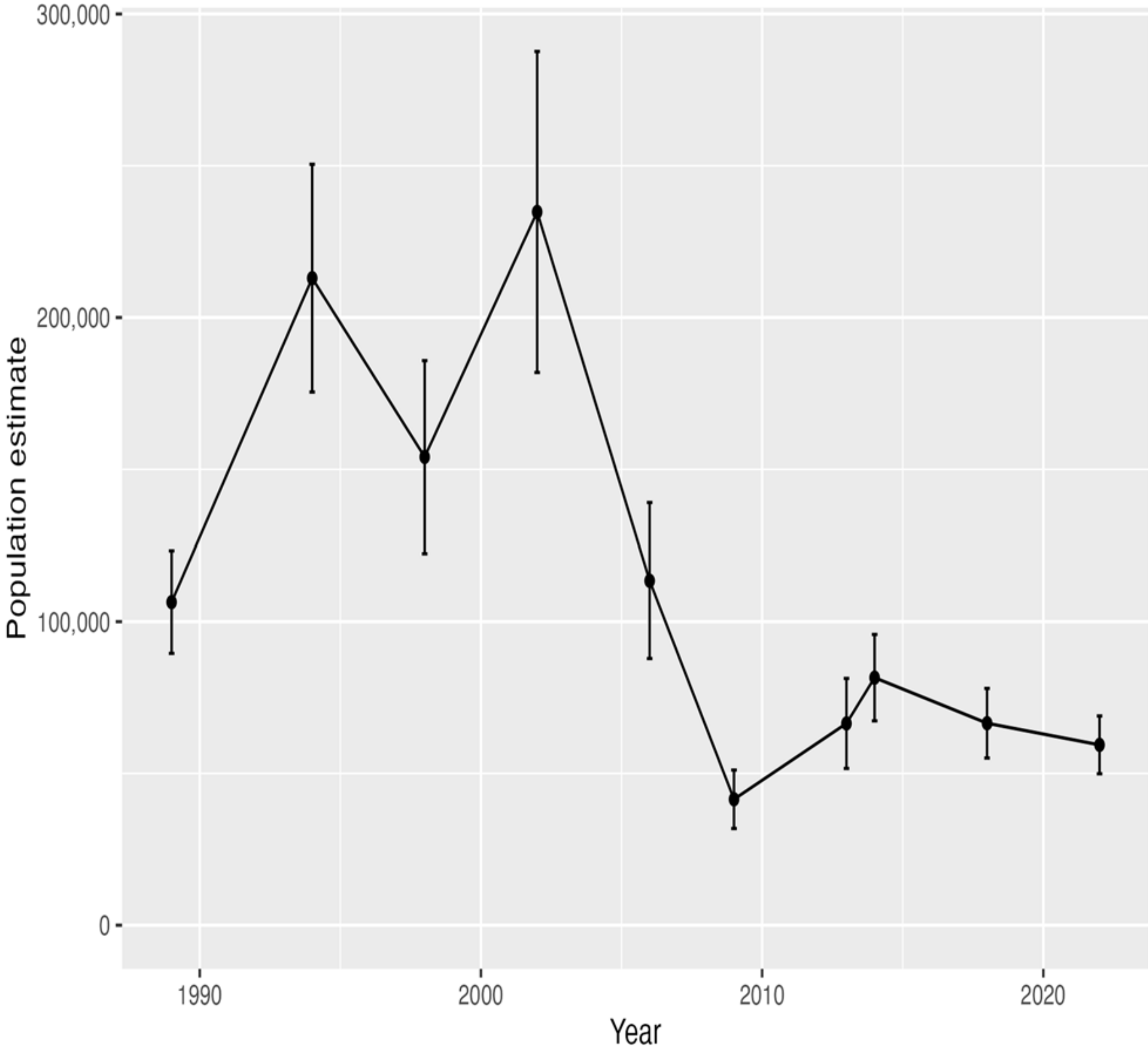


Figure 6: Buffalo population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.2 Impala distribution, density and population trend

Impala was among the most abundant antelope species in the ecosystem (14,031 ± 2,016 SE) (Table 2). The highest estimate was in Nyerere NP (5, 642 ± 1,362 SE), followed by Selous GR (3,482 ± 901 SE), Mikumi NP (1,723 ± 870 SE), and Outside East – Liwale (2,241 ± 722 SE) (Appendix 4 & Fig 7). In Mikumi NP, the highest concentration was observed in the northern part, and none were observed in the central half of the area. In Nyerere NP, the highest density was observed in the north-eastern part (Matambwe sector), which are grassland-dominated areas and the few observations were in the central part, whereas the southern part had no observations at all. In the Selous GR, the highest concentration was in the eastern part, and few observations were in other parts. Outside the ecosystem, the East-Liwale had the highest concentration, especially in the north, central and southern parts.

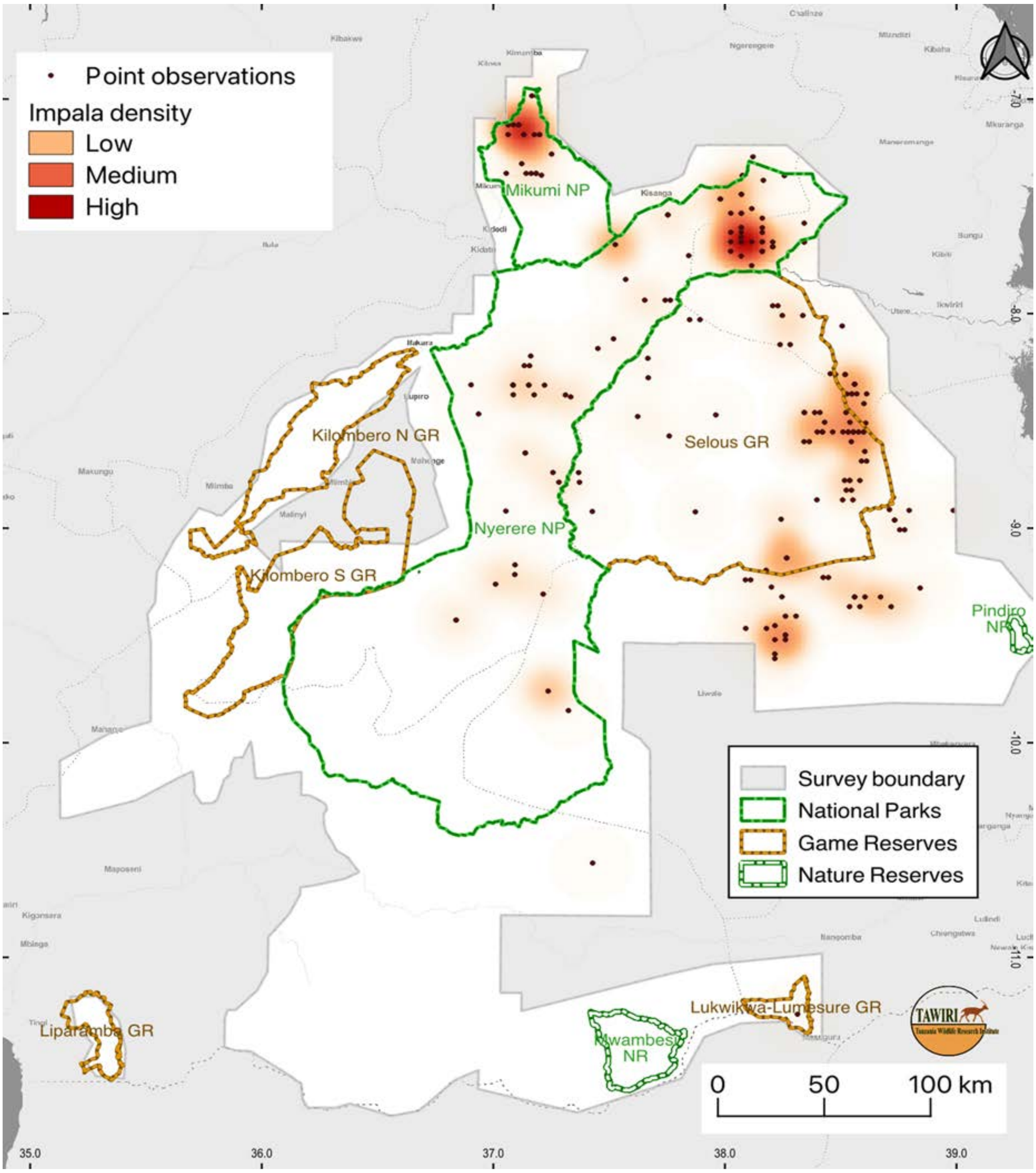


Figure 7: Dry season impala distribution and density in the ecosystem in 2022

Additionally, low concentrations were observed in the central and southern parts of Selous GR. There were no observations of Impala in Kilombero GCA, Mahenge and the Selous-Niassa corridor (Fig. 7). A long-term trend indicates Impala population has fluctuated in the last decades (Fig. 8). Lack of observations in the southern part of the Mikumi NP, Nyerere NP and in other areas could be associated with the fact that the areas are dominated by woodland habitat type, in which is unfavourable habitat for impala.

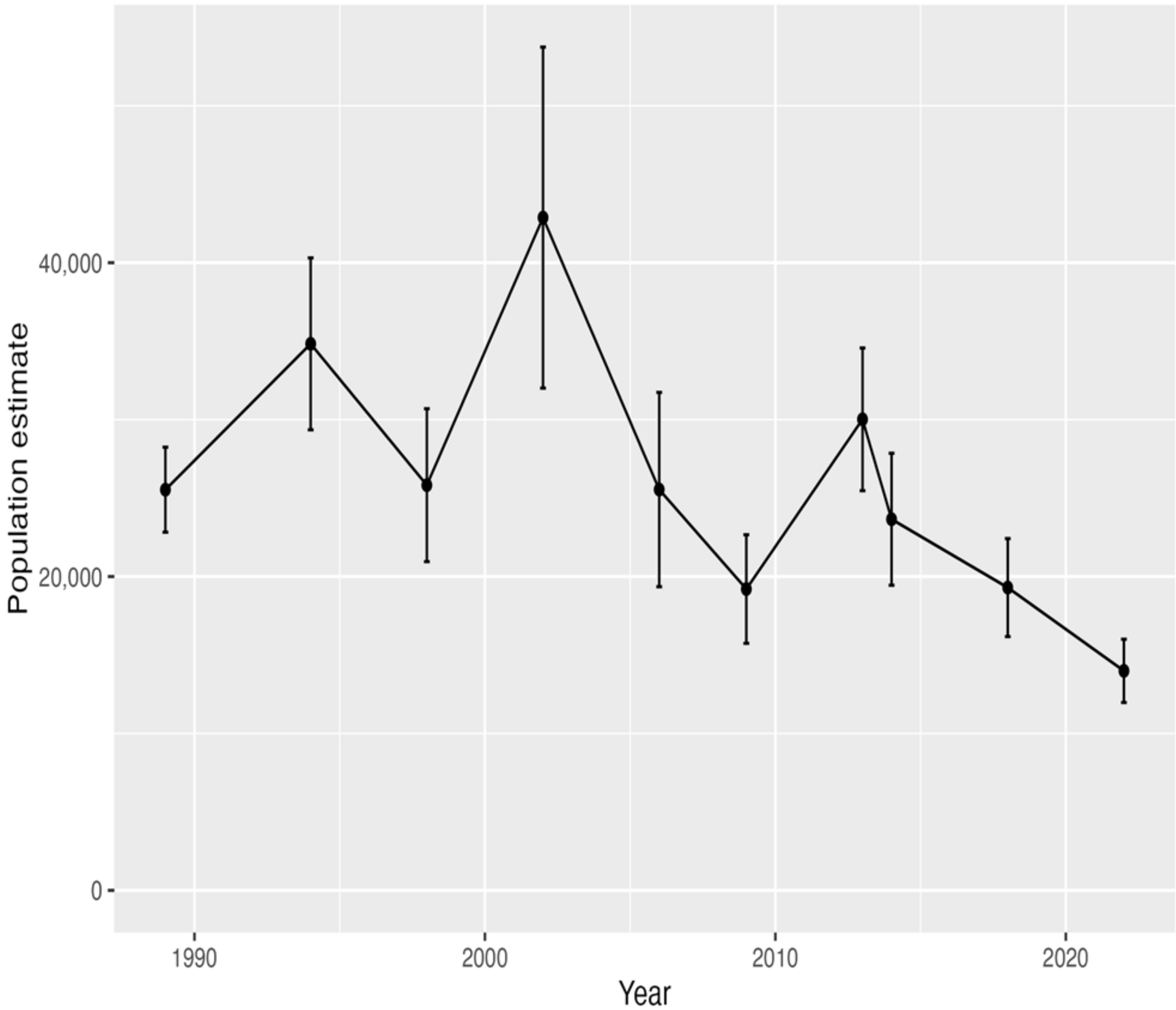


Figure 8: Impala population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.3 Hippo distribution and density

Hippo population stood at 29,071 ± 4,146 SE (Table 2). The highest population estimate was observed within the boundaries of Nyerere National Park (21,963 ± 3,808 SE), followed by Selous Game Reserve (6,279 ± 1,590 SE) and the Out Southeast (Liwale) administrative area (609 ± 379 SE). However, only a limited number of hippos were found in Masasi and Out Mikumi administrative areas (see Appendix 4). The distribution pattern of hippos closely aligns with the primary river system within Nyerere National Park and Selous Game Reserve (Fig. 9) and short-term trend indicates a stable population (Fig. 10).

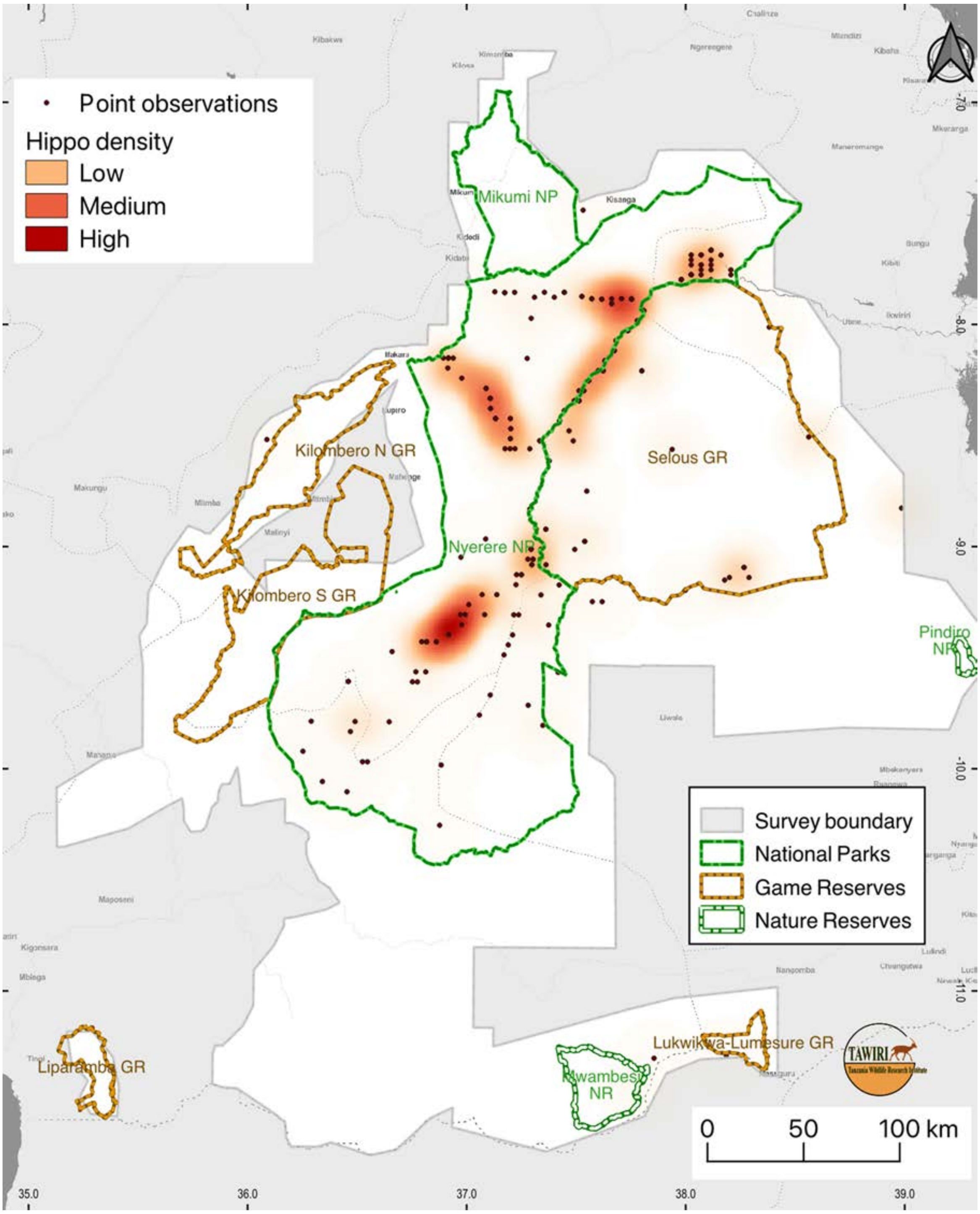


Figure 9: Dry season hippo distribution and density in the ecosystem in 2022

The highest concentration of hippos was observed in Nyerere National Park, particularly along the Rufiji, Kilombero, Luwegu, and Lung'onya rivers. It is worth noting that the Systematic Reconnaissance Flight (SRF) method may not be the most accurate approach for estimating hippo and crocodile populations, thus emphasizing the need for regular specialized counts in these contexts.

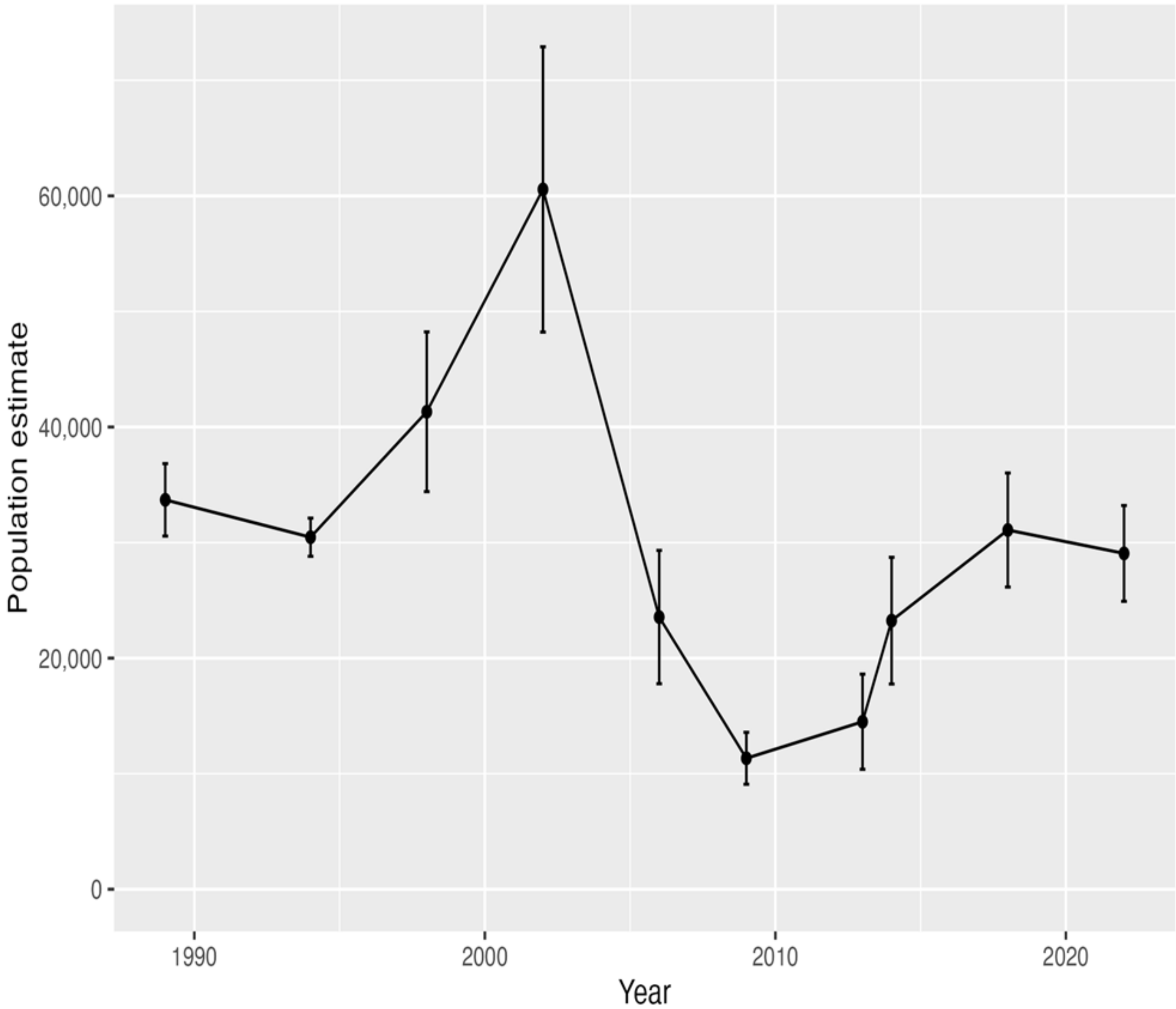
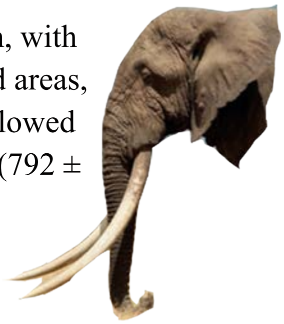


Figure 10: Hippo population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.4. Elephant distribution, density and population trend



Elephants emerged as one of the most prevalent species within the ecosystem, with an estimated population of 20,006 ± 1,793 SE (Table 2). Among the surveyed areas, Nyerere NP exhibited the highest estimate of elephants (8,303 ± 929 SE), followed by Selous Game Reserve (7,281 ± 1,248 SE) and the Selous-Niassa corridor (792 ± 324 SE) (Appendix 4). The species displayed a wide distribution across the surveyed area, with only a few exceptions noted in Outside Mikumi , Selous Outside North, Selous Outside West, the Central and Southern parts of the Selous-Niassa corridor, and Liparamba GR (Fig.11). In Nyerere NP, elephants were observed throughout the park. The most concentrated populations of elephants were observed in the southeastern, central, and southern Selous GR, as well as in the central area of Mikumi National Park (Fig.11).

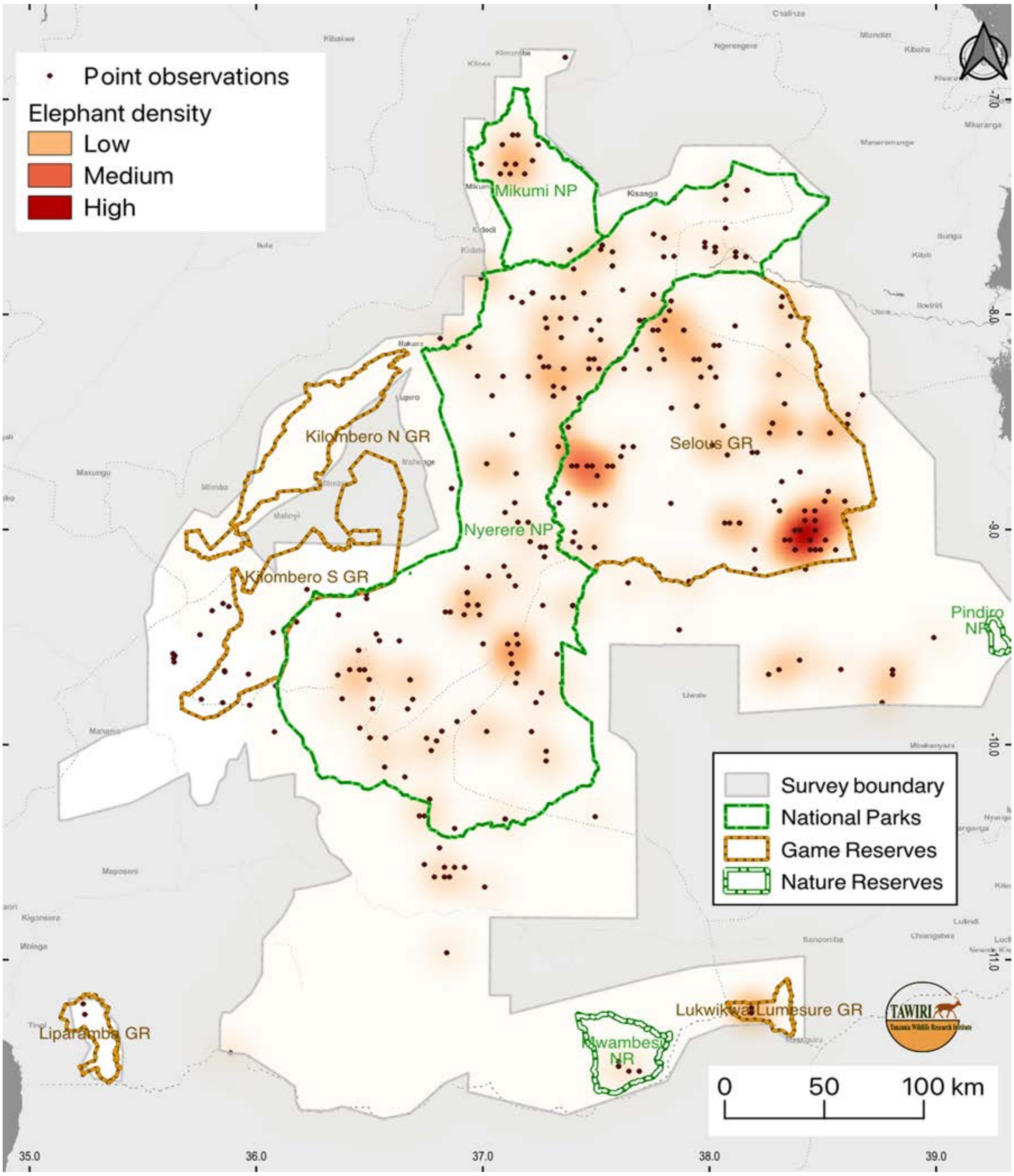


Figure 11: Dry season elephant distribution and density in the ecosystem in 2022

Additionally, notable elephant populations were identified in areas outside Southeast (Liwale Wildlife Management Area) and Mwambesi Nature Reserve. Conversely, areas with relatively lower density and restricted distribution included Outside West (Mahenge), the southern and western sections of the Selous-Niassa corridor, and Liparamba Game Reserve (Appendix 4). Although the long-term trend indicates a decline in the elephant population, the short-term trend suggests a stable population (Fig.12).

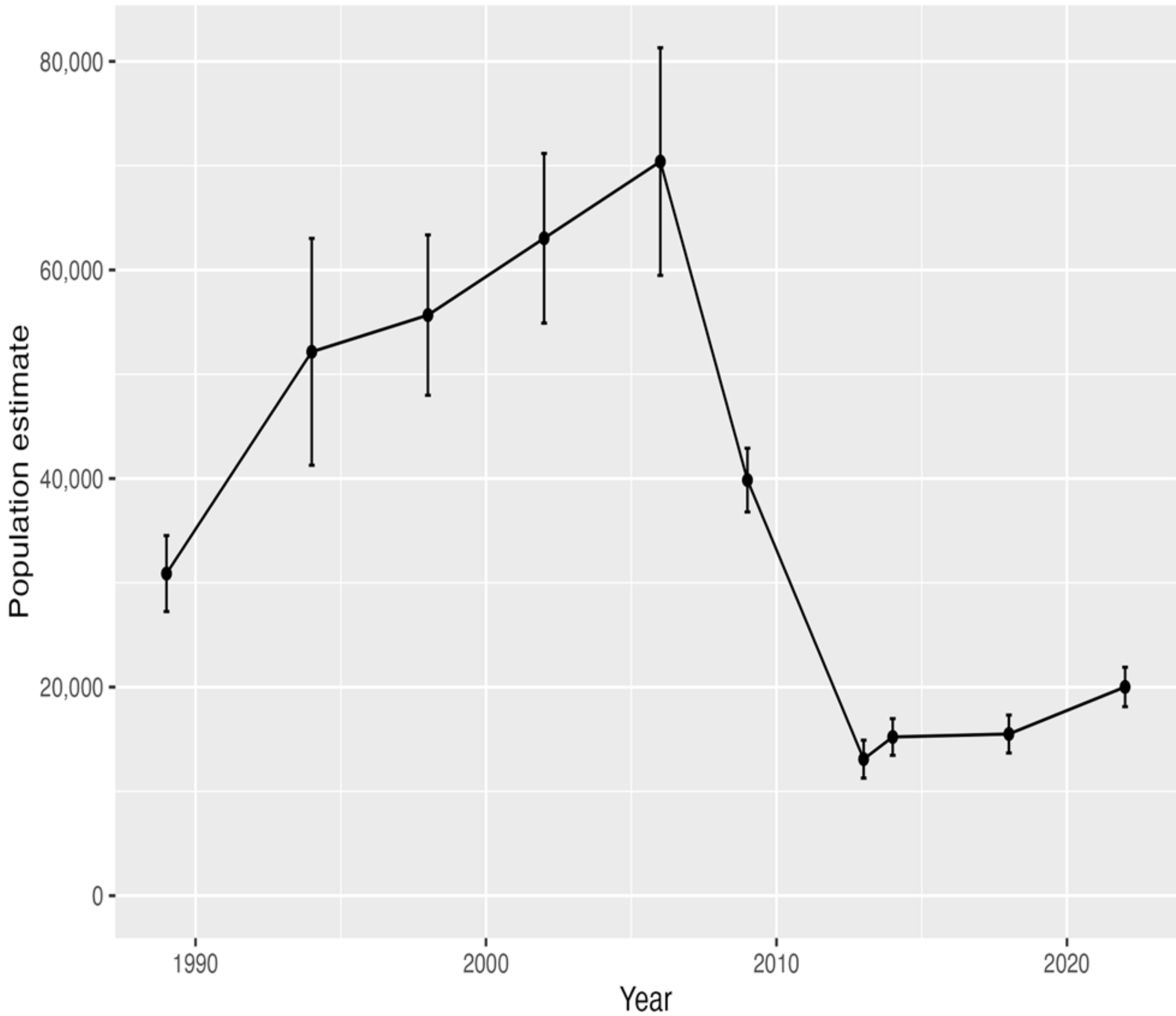


Figure 12: Elephant population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.5 Elephant carcass distribution and density

Elephant carcasses are visible for up to several years from the air, usually as bones, though most disappear in the first year after mortality. Determining carcass estimate and their locations is a vital part to ascertaining conservation efforts. Three (EC3) and Six very old elephant carcasses (EC4) were sighted (in strip) and one EC4 (out of strip) in the north-eastern part of Nyerere NP (Matambwe sector), northern and southern Selous GR and northern Mikumi NP (Fig. 13), with only one (EC1) record of elephant carcass (near Lukuyu Seka area) that was less than one year old, believed to have died naturally as the tusks were found intact (out of strip). The carcass ratio (ratio of dead to living + dead elephants, a measure of mortality in the system) has dropped significantly from 16% in 2018 to 0.8% in 2022 (Table 3). This ratio implies little or no excess mortality in the ecosystem and a population that should be increasing. Though the statistics on elephant numbers from 2018 to 2022 do not show a significant increase, the trends from 2014 onwards strongly suggest that the population is naturally increasing (Fig.12).

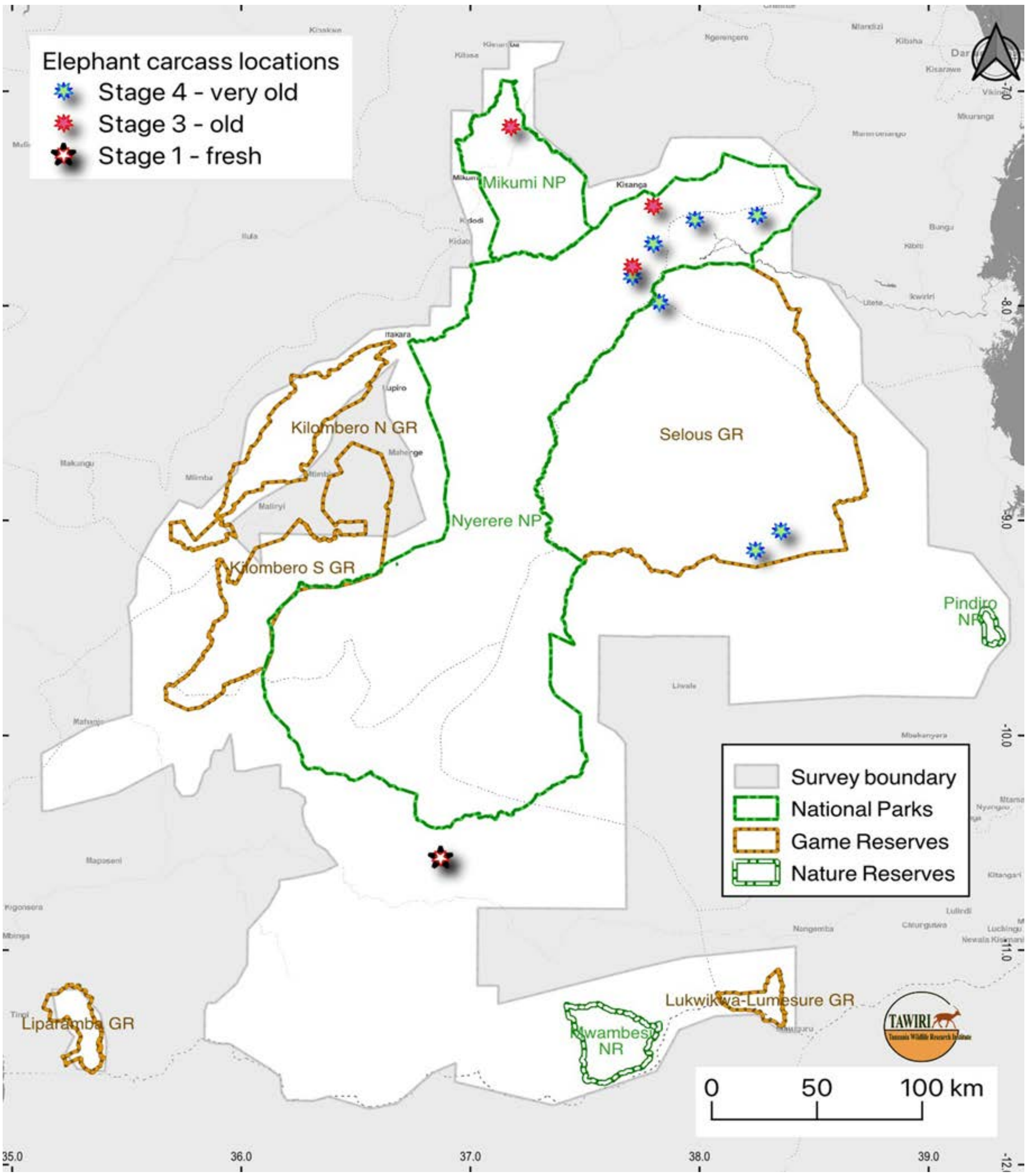


Figure 13: Dry season elephant carcass distribution and density in the ecosystem in 2022 including the one seen outside the strip

3.3.6 Kongoni (hartebeest) distribution and density

Kongoni were estimated at 18,361 ± 1,853 SE over the entire survey area (Table 2). Administratively, Nyerere NP recorded the highest population (7,186 ± 1,286 SE), followed by Selous GR (5,558 ± 884 SE), and Outside Southeast (Liwale block) (3,926 ± 800 SE) (Appendix 4). In contrast, there were no observations in Kilombero GCA (now Kilombero GR), Ngarambe-Tapika, Kidunda-Gonabis, Mbalika, Lukwika-Lumesule, Mwambesi and Mikumi West (Fig. 14). In Nyerere NP, the highest concentration was observed in Matambwe, Central and north-western parts, and relatively few in the southern part.

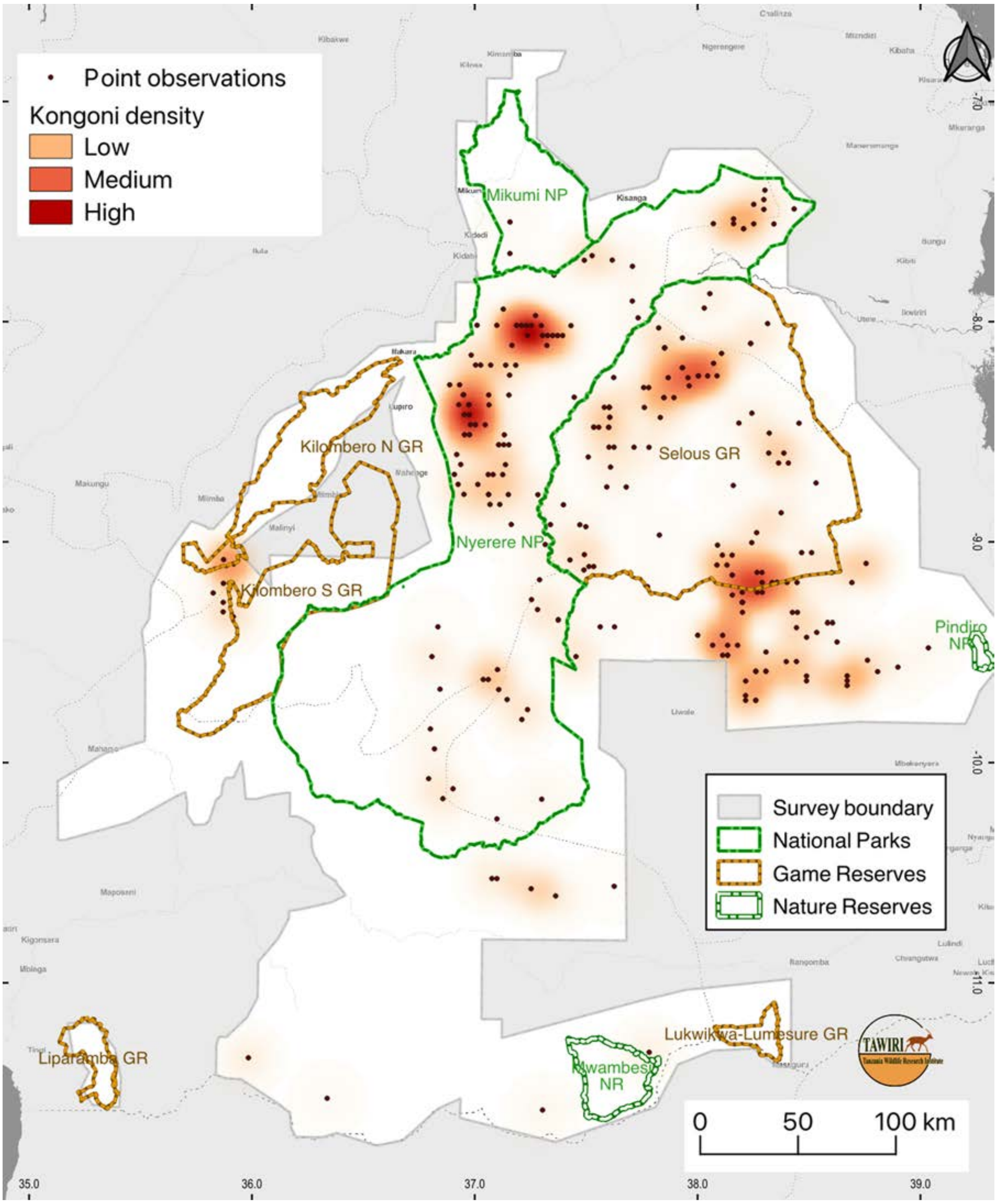


Figure 14: Dry season kongoni distribution and density in the ecosystem in 2022

In Selous GR, the north-western part towards the south-western and the southern part both had the highest densities. The Liwale block registered the highest and well distribution pattern, especially in the central and eastern parts. There were few observations in Mikumi NP, Kilombero GCA (GR) and Selous-Niassa corridor. The long-term trend indicates an increasing kongoni population in the ecosystem (Fig.15).

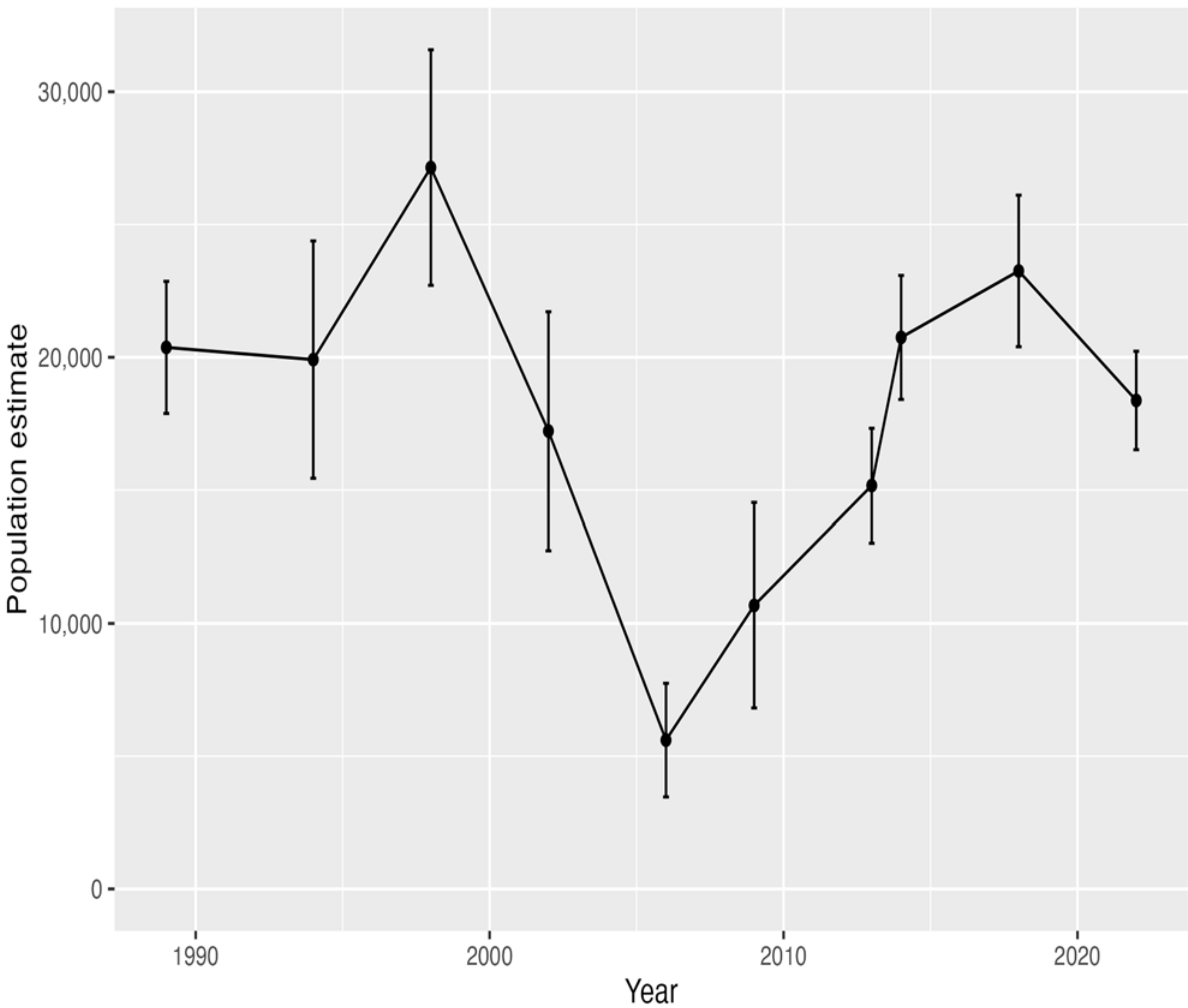


Figure 15: Kongoni population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.7. Wildebeest distribution and density

Wildebeest were estimated at a population of 19,060 ± 2,906 SE (Table 2). The highest estimate of wildebeest was observed in Selous GR of which were estimated at (9,867 ± 2,083 SE), followed by Nyerere NP (4,702 ± 1,251 SE) and Mikumi NP (2,894 ± 1,274 SE) (Appendix 4). There were no observations in the Kilombero GCA (GR), Kidunda-Gonabis, Mahenge, Mbalika, Selous-Niassa corridor, Lukwika-Lumesule and Mwambesi, as well as Mikumi-west and Liparamba GR. Spatially, in Nyerere NP, the highest concentration was in Matambwe sector, whereas, in Selous GR, the highest concentration was in the northern part, downwards south towards the eastern boundary, and from the central-western part towards the southern end of the reserve.

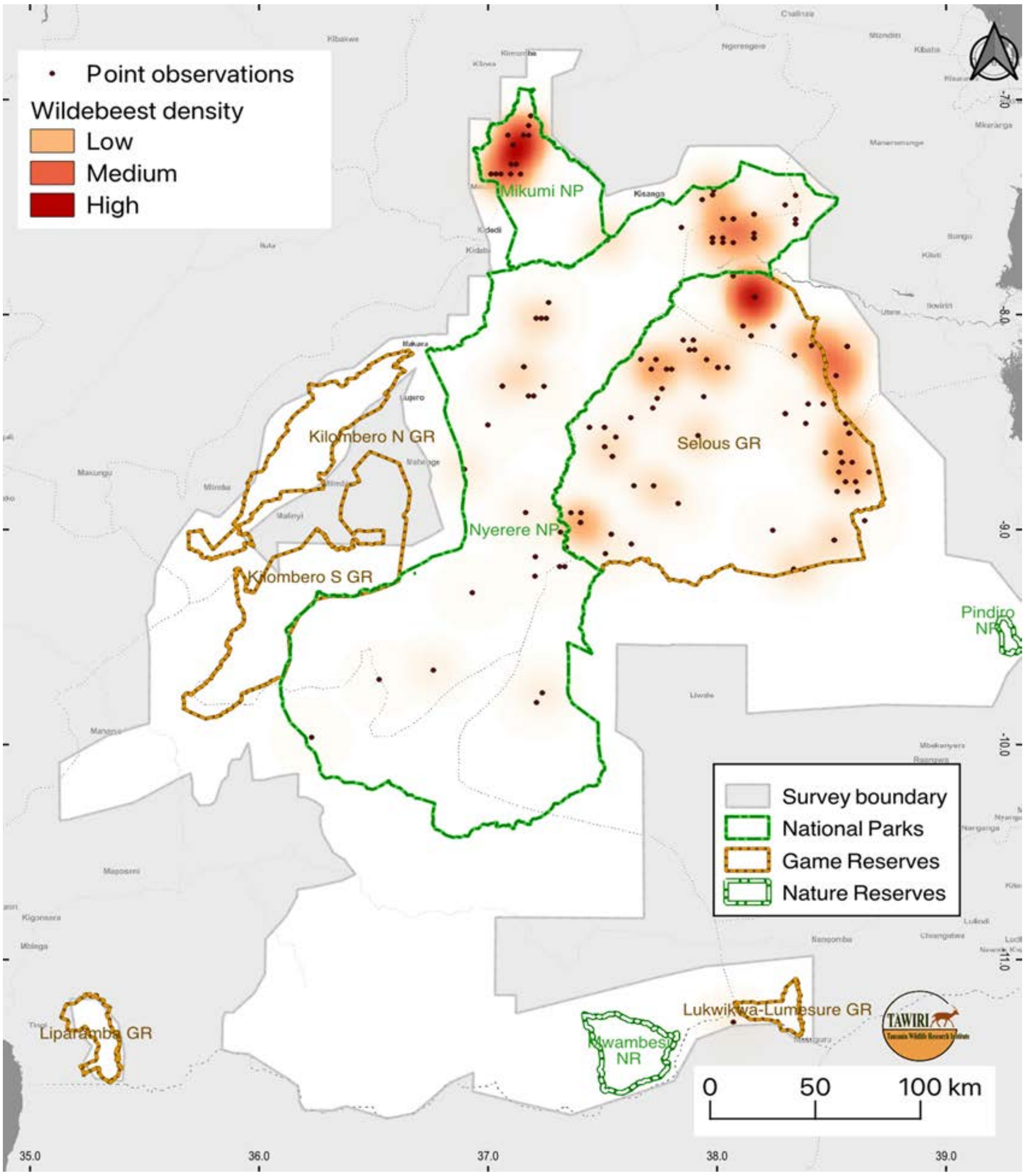


Figure 16: Dry season wildebeest distribution and density in the ecosystem in 2022

The Mikumi NP population was concentrated in the northern part (Fig. 16) and the population has remained stable in recent years although long-term trends indicate a decling pupulation (Fig. 17). Future work should investigate the reason for this decline and the specific areas where it is happening.

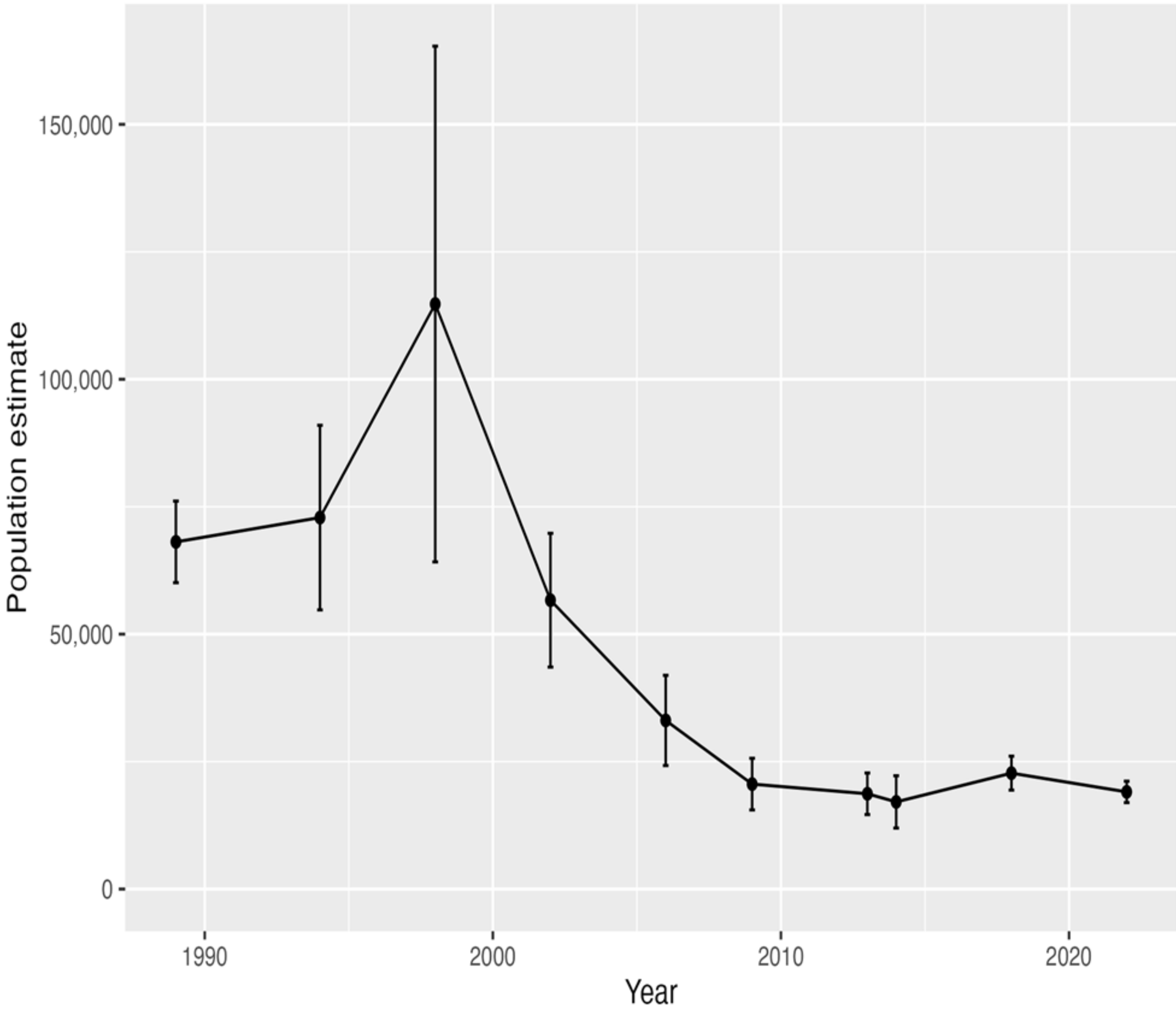


Figure 17: Wildebeest population trend in the ecosystem from 1989 to2022 (vertical bars indicate SE)

3.3.8 . Zebra distribution and density

Zebra were estimated at 16,669 ±1,828 SE (Table 2). The highest estimate of zebra was observed in Selous GR (7,088 ±1,021 SE), followed by Nyerere NP (5,485 ± 792 SE) and Outside Mikumi (858 ±803 SE) (Appendix 4). Spatial Distribution in the Selous GR was in the north-western part and on the eastern side of the reserve. There was also high density in the southern part.

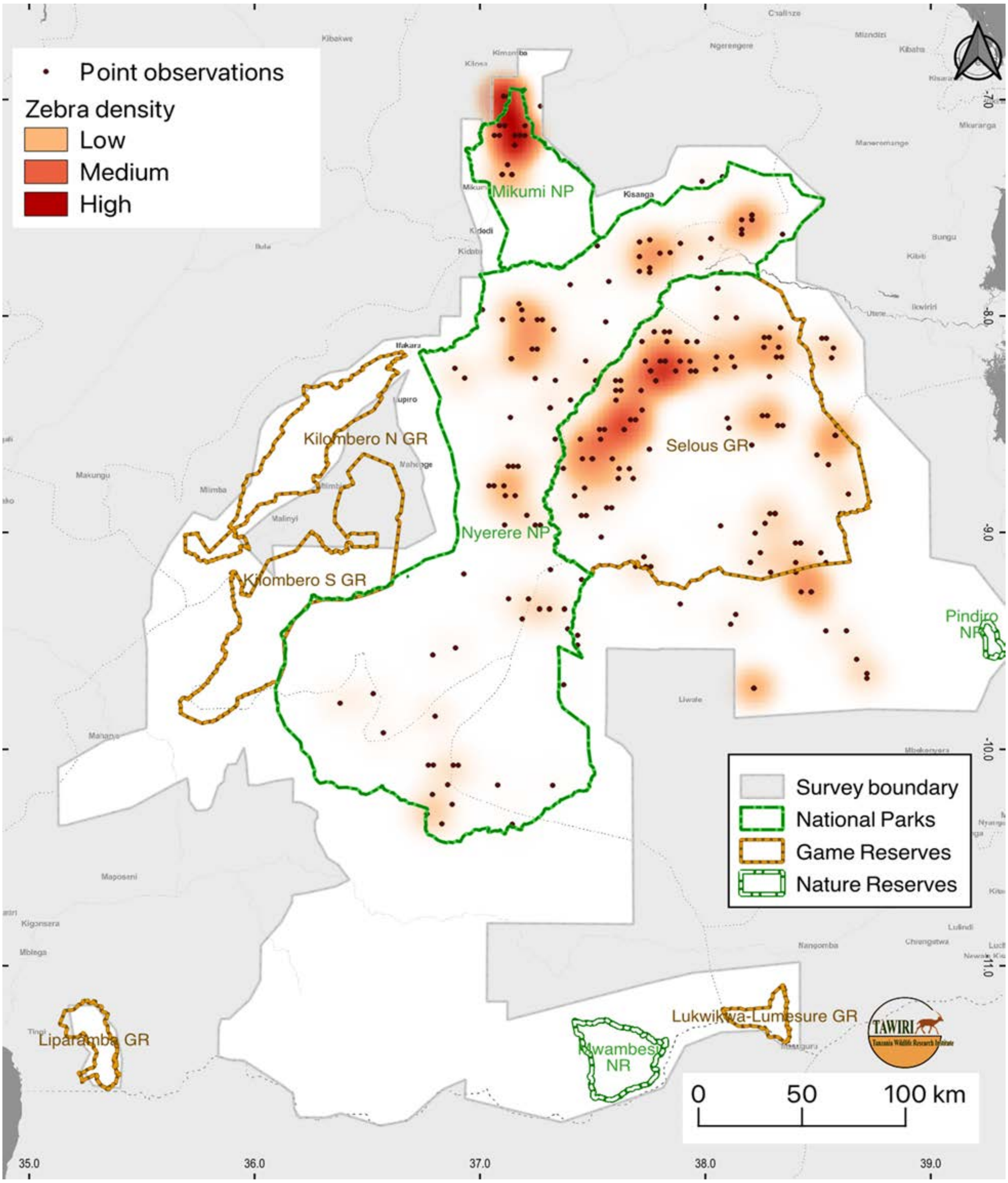


Figure 18: Dry season zebra distribution and density in the ecosystem in 2022

The northern half of the Nyerere NP recorded the highest concentration compared to the rest, and no observations were recorded in the eastern and western parts of the park. In Mikumi NP, the highest population was concentrated at the northern tip, and no observations were recorded on the southern side (Fig. 18). The long-term trend suggests a population that has stabilised below 20,000 down from high 36,000 (Fig. 19).

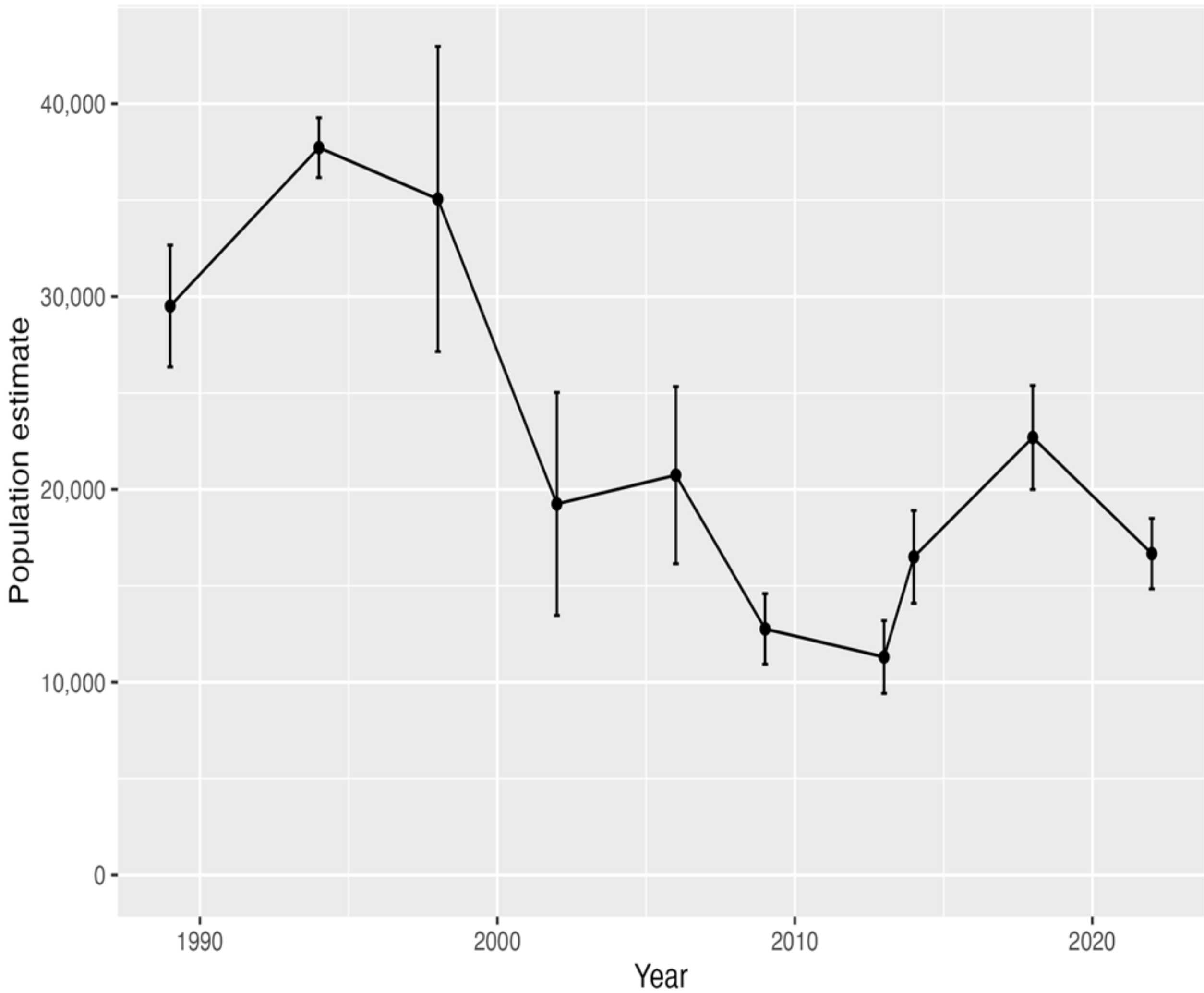


Figure 19: Zebra population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.9. Sable antelope distribution and density

Sable antelope population in the entire survey area were estimated at 9,008 ± 1,379 SE (Table 2). Results indicate that the highest population estimates were observed in Nyerere NP (2,831 ± 576 SE), followed by Selous GR (1,231 ± 317 SE) and Mwambesi NR (412 ± 279 SE) (Appendix 4). There was no observation in Kilombero GCA (GR), Masasi, Mikumi NP, Ngarambe-Tapika, Out Mikumi, Lukwika-Lumesule, Liparamba GR and Kidunda-Gonabis (Fig. 20).

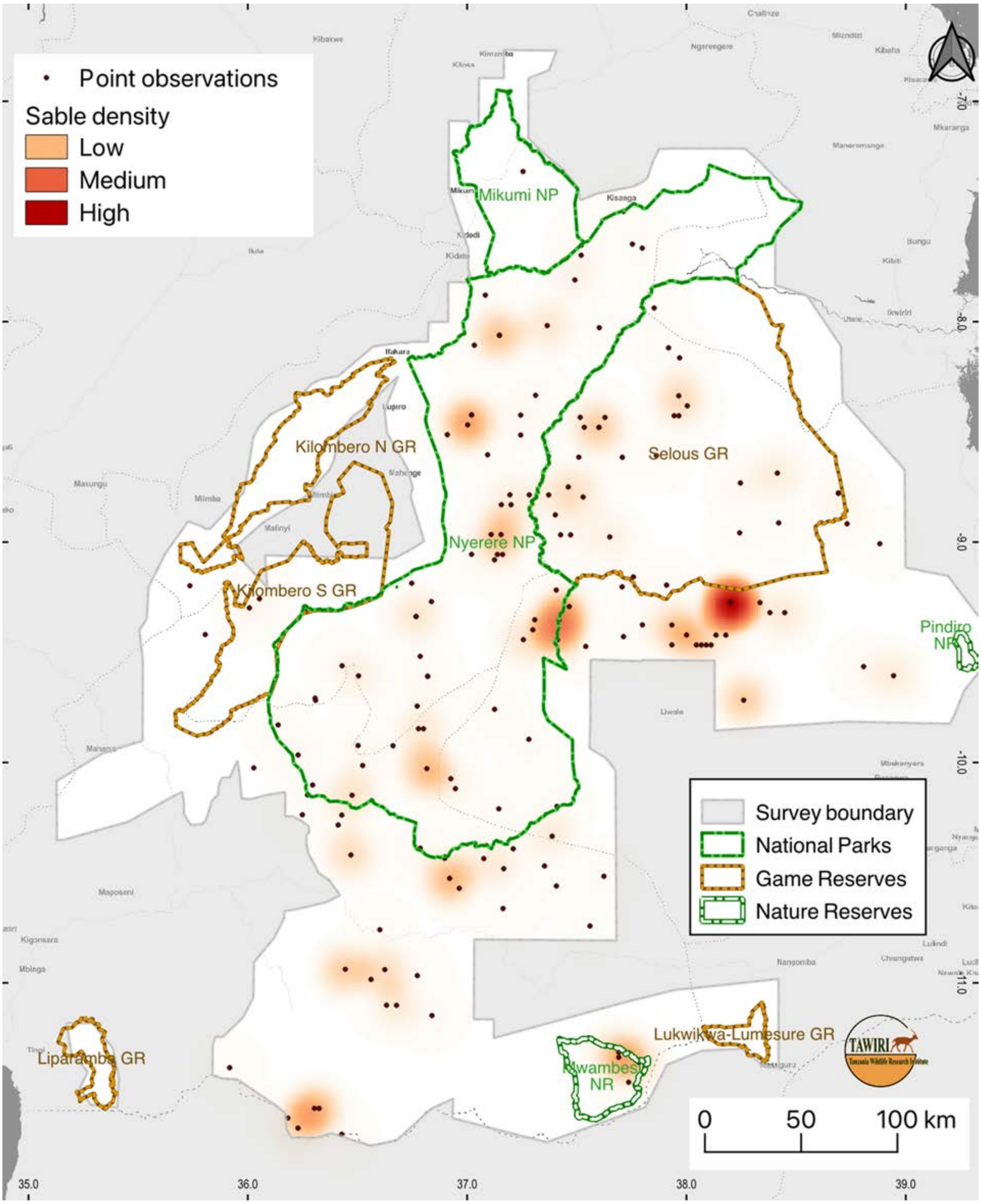


Figure 20: Dry season sable antelope distribution and density in the ecosystem in 2022

In Nyerere NP, they were widely distributed across the entire area, with the highest concentration in the eastern part. A high concentration in Selous GR was in the western half of the reserve (western boundary from north to south) and considerable concentration was recorded in Liwale and Selous-Niassa wildlife corridor. The short-term trend indicates a stable population but long-term species population trend indicates an increasing population (Fig. 21).

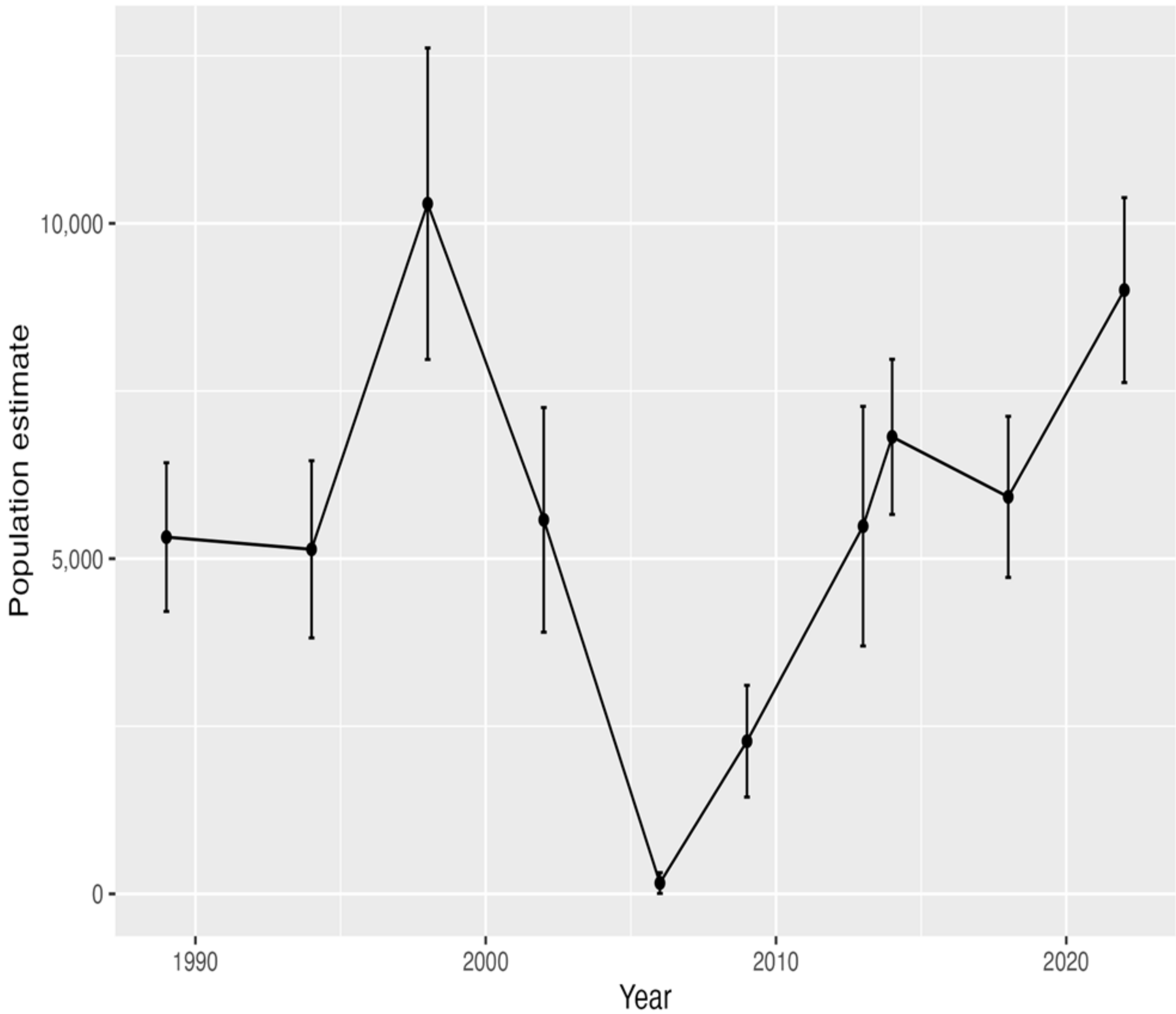


Figure 21: Sable antelope population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.10. Eland distribution and density

Eland was estimated to have a population of 4,902 ± 1,256 SE individuals (Table 2), with Liwale having the highest population estimate (1,434 ± 795 SE), followed by Nyerere NP (1,363 ± 492 SE) and Selous GR (879 ± 392 SE) (Appendix 4). Furthermore, there were no observations in Kilombero GCA (GR), Masasi, Ngarambe-Tapika, Liparamba GR, Mikumi (Out), Lukwika-Lumesule, Mwambesi NR, and Mikumi-West (Fig. 22).

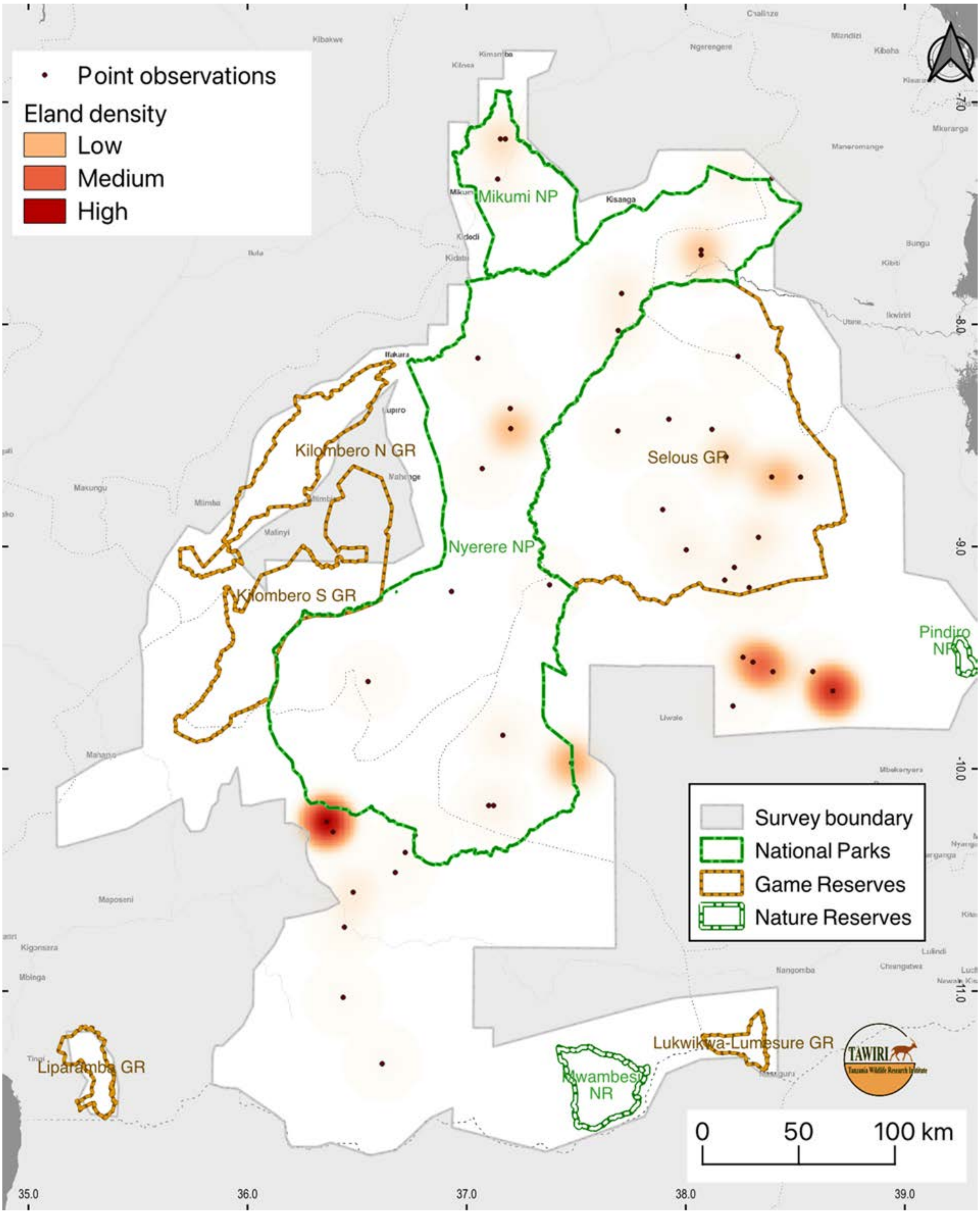


Figure 22: Dry season eland distribution and density in the ecosystem in 2022

No major changes in the population from long term trends stabilising around 4,000 individuals since 1990s (Fig. 23). In Liwale, eland was mostly concentrated in the southern part, whereas in Nyerere NP were in the northern, and central part, and in Selous GR, the highest observations were in the eastern side of the reserve.

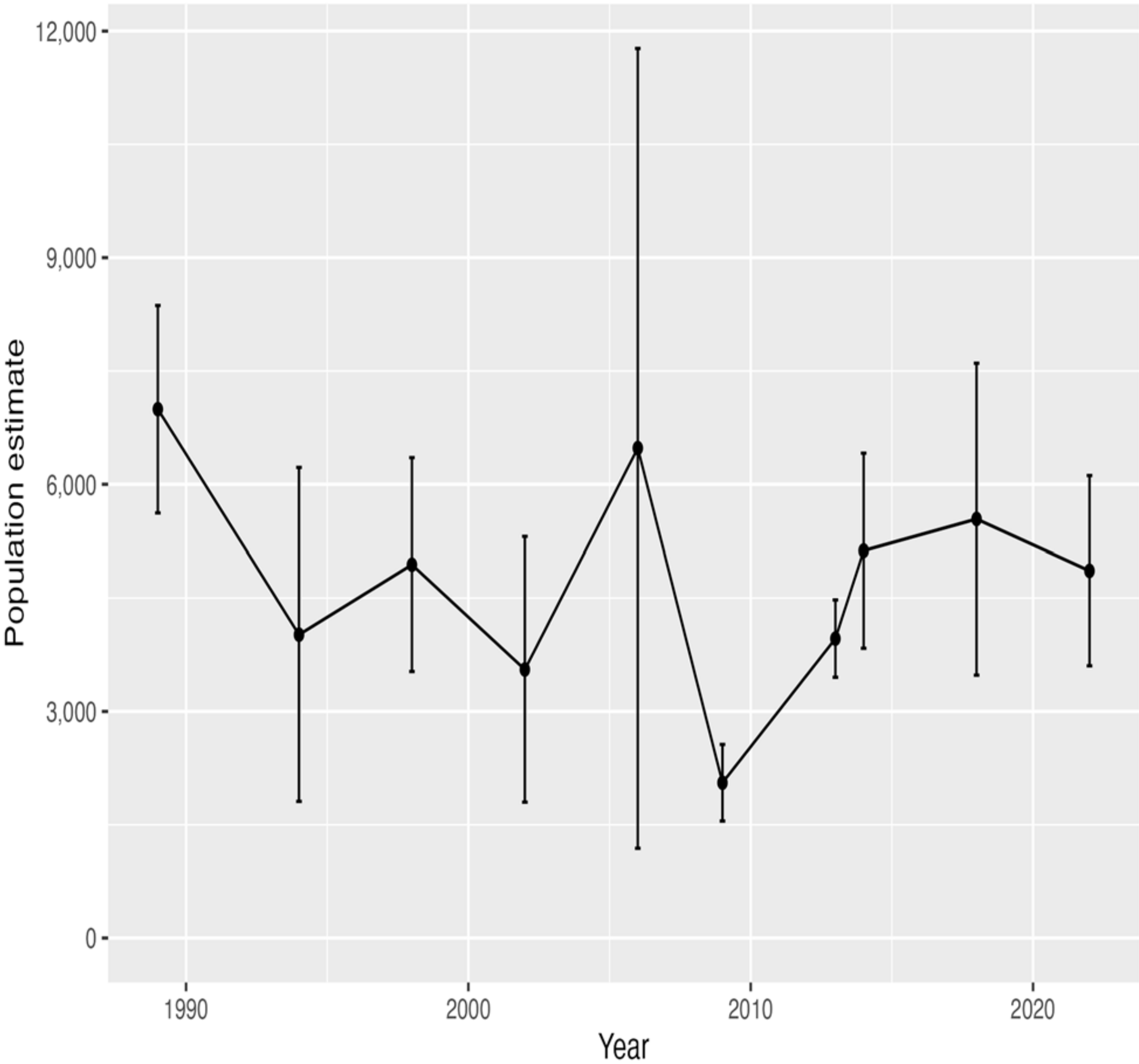


Figure 23: Eland population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.11. Waterbuck distribution and density

The population estimate for waterbuck indicates a total of 6,156 ± 897 SE individualls (Table 2), of which the majority were estimated in the Nyerere NP (4,491 ± 786 SE), followed by Selous GR (827 ± 350 SE), whereas for other species is shown in (Appendix 4). In Nyerere NP, the highest concentration was found in the central and southern parts of the park. Low concentrations were observed in the outside west (Mahenge) (Fig. 24).

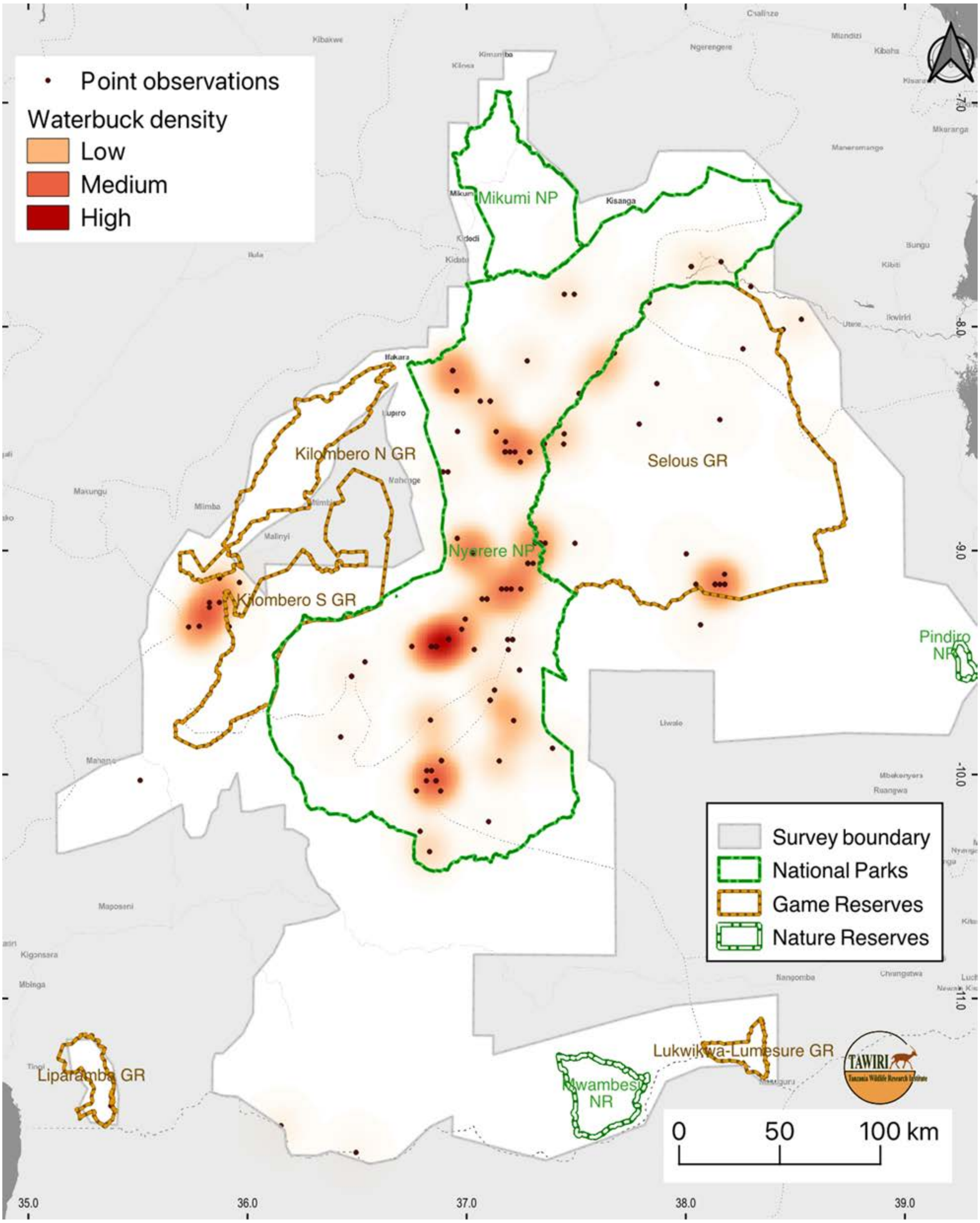


Figure 24: Dry season waterbuck distribution and density in the ecosystem in 2022

No observations were recorded in Kilombero GCA (GR), Masasi, Kidunda-Gonabis, Lukwika-Lumesule, Mwambesi NR and Mikumi west. Population trend indicates a stable population from 2005 to 2022 (Fig. 25).

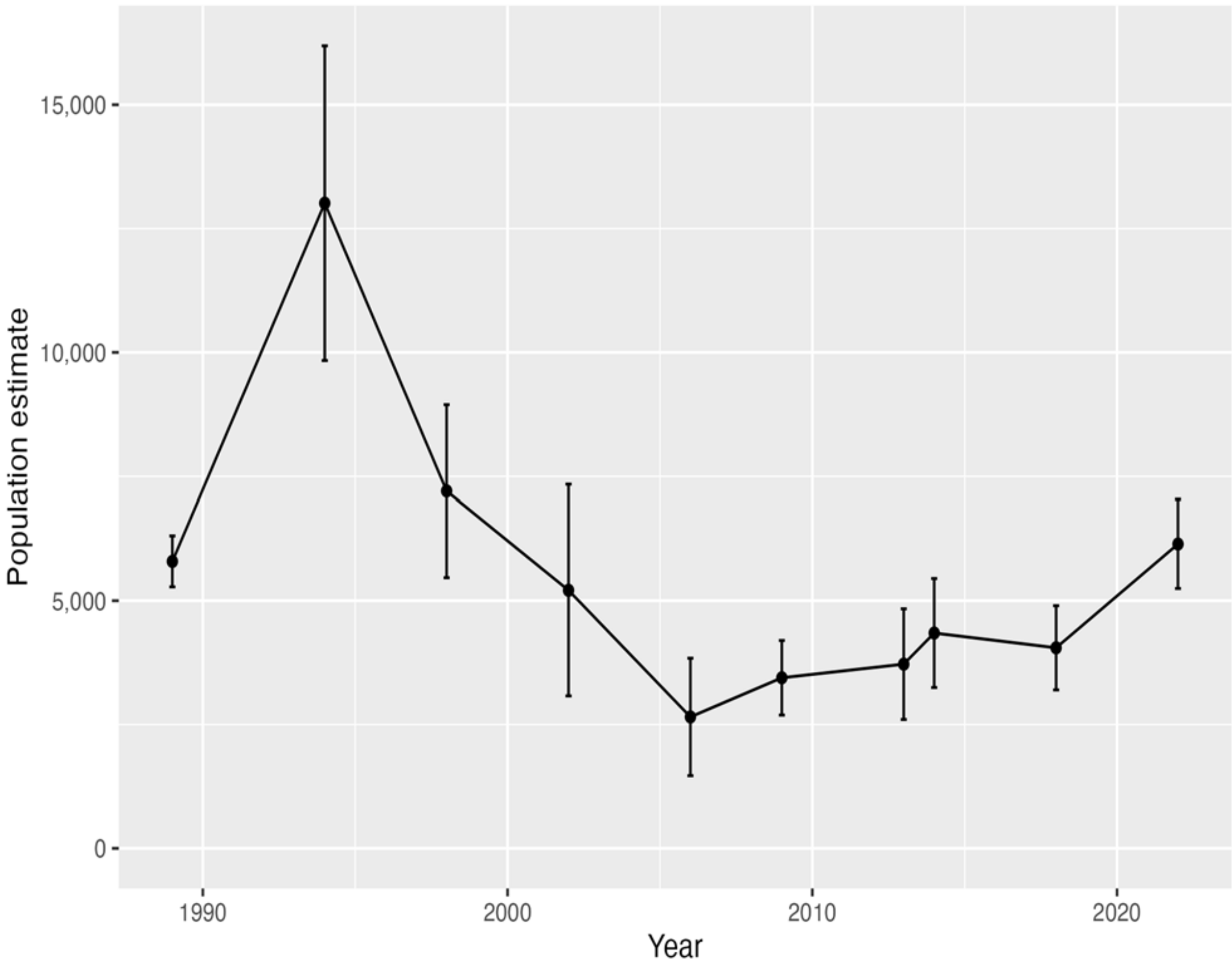


Figure 25: Waterbuck population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.12. Giraffe density and distribution

Historically, the spatial distribution of giraffe is restricted only to the northern part of the ecosystem; no records for giraffes were observed south of the Ruaha and Rufiji rivers. The current population indicates there is a total of 1,679 ± 555 SE individuals (Table 2), with Nyerere NP (Matambwe sector) registering the highest (1,277 ± 520 SE) followed by Mikumi NP (401 ± 194 SE) (Appendix 4).

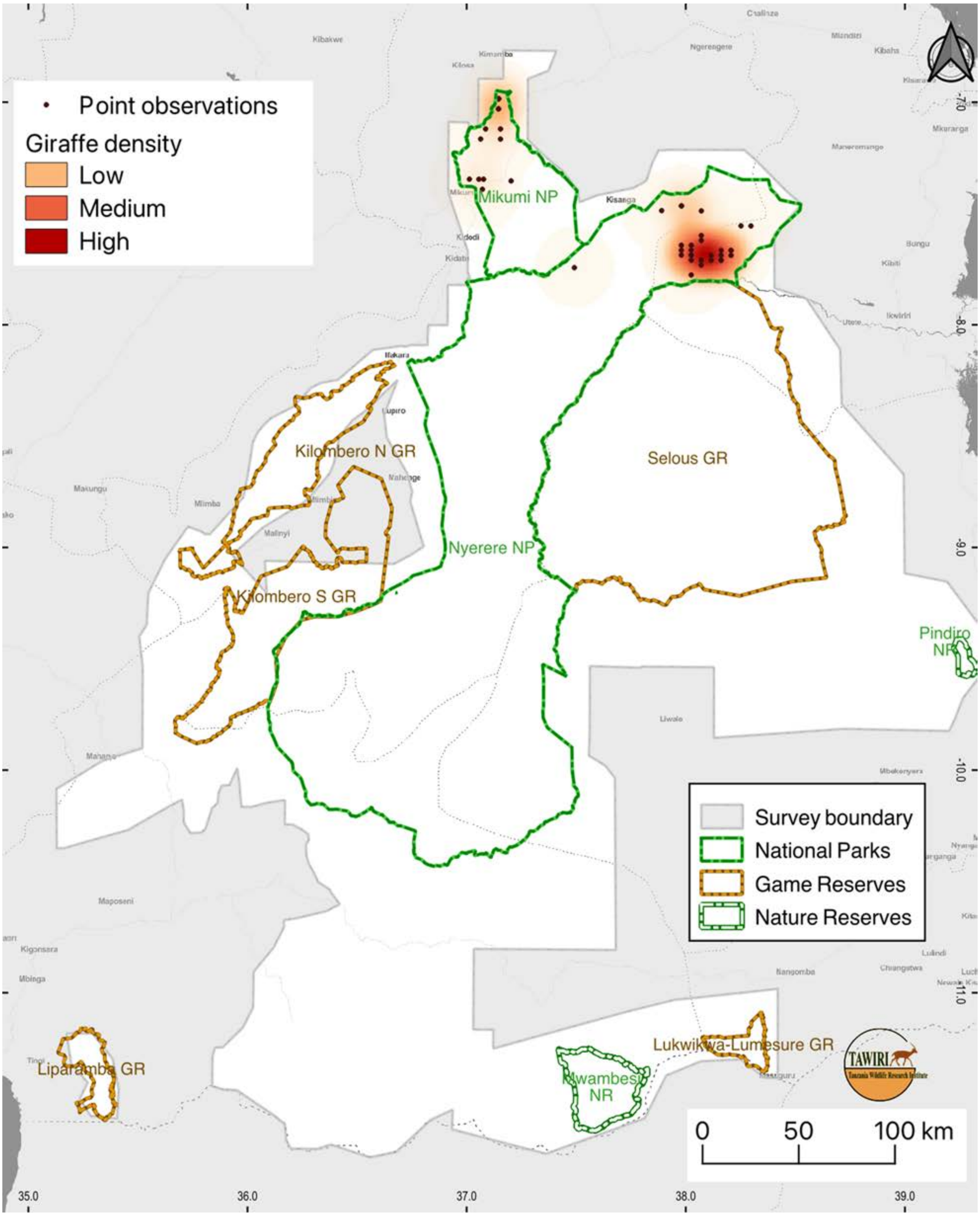


Figure 26: Dry season giraffe distribution and density in the ecosystem in 2022

The highest recorded concentration was in the southern part of Matambwe and in Mikumi north and there were no observations were recorded in Kilombero GCA (GR), Masasi, Ngarambe-Tapika, Out Mikumi, Kidunda-Gonabis, and Mahenge (Fig.26). Giraffe numbers may have declined from an estimated high of over 6,000 in 2002 (Fig. 27).

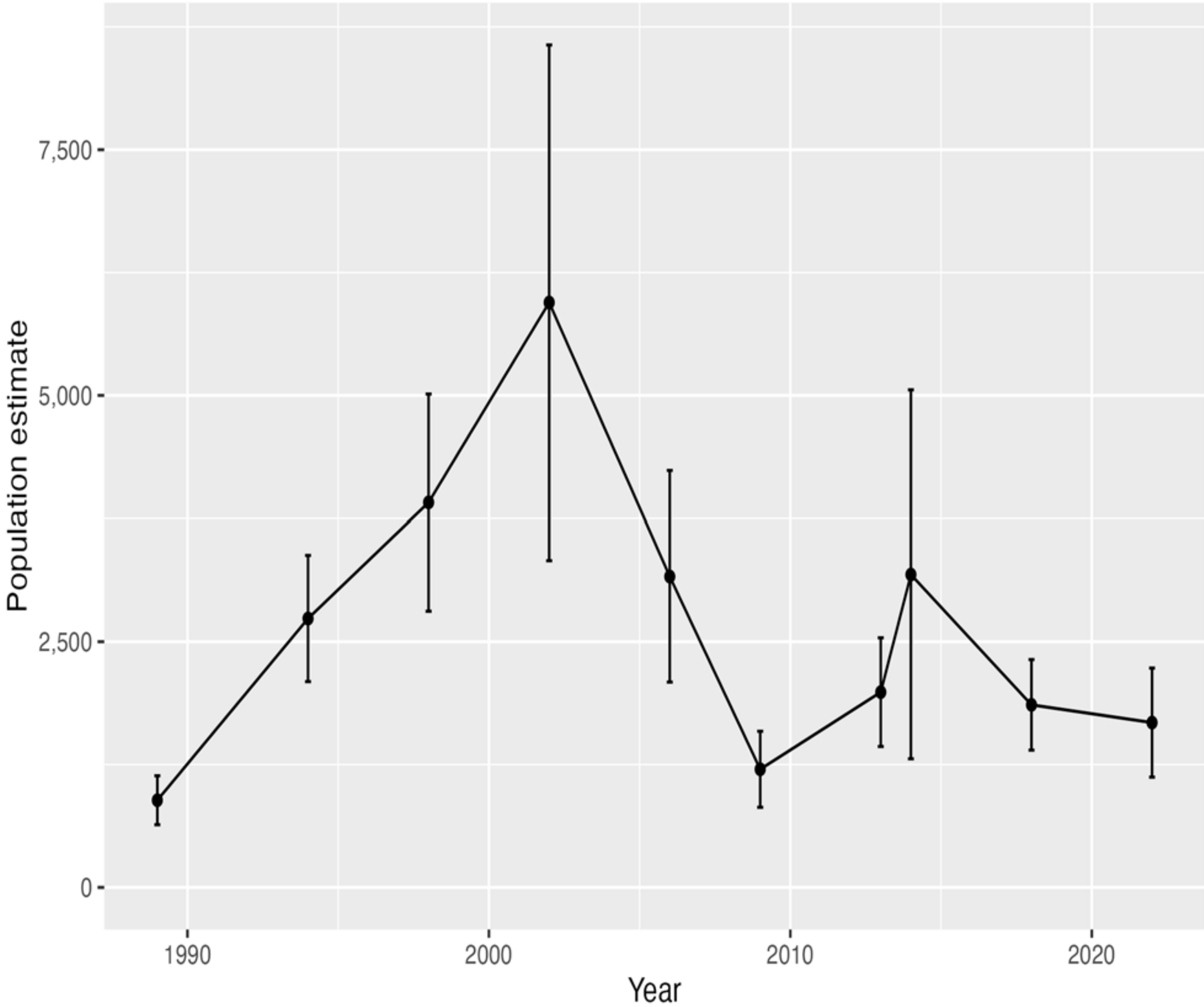


Figure 27: Giraffe population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.13. Warthog distribution and density

Warthogs had a population estimate of 13,806 ± 1,475 SE individuals (Table 2). Among the administrative blocks, Liwale exhibited the highest population with 5,270 ± 1,256 SE individuals, followed by Selous GR with 4,362 ± 587 SE individuals, Nyerere NP with 2,005 ± 301 SE individuals, and Selous-Niassa with 686 ± 254 SE individuals (Appendix 4). In Liwale, the central part, as well as the eastern and western sides, recorded a high presence of warthogs. In Selous GR, the highest concentration was observed in the north-eastern part, extending towards the southern end along the boundary, while the species was widely distributed with low concentration in other areas within the reserve (Fig. 28).

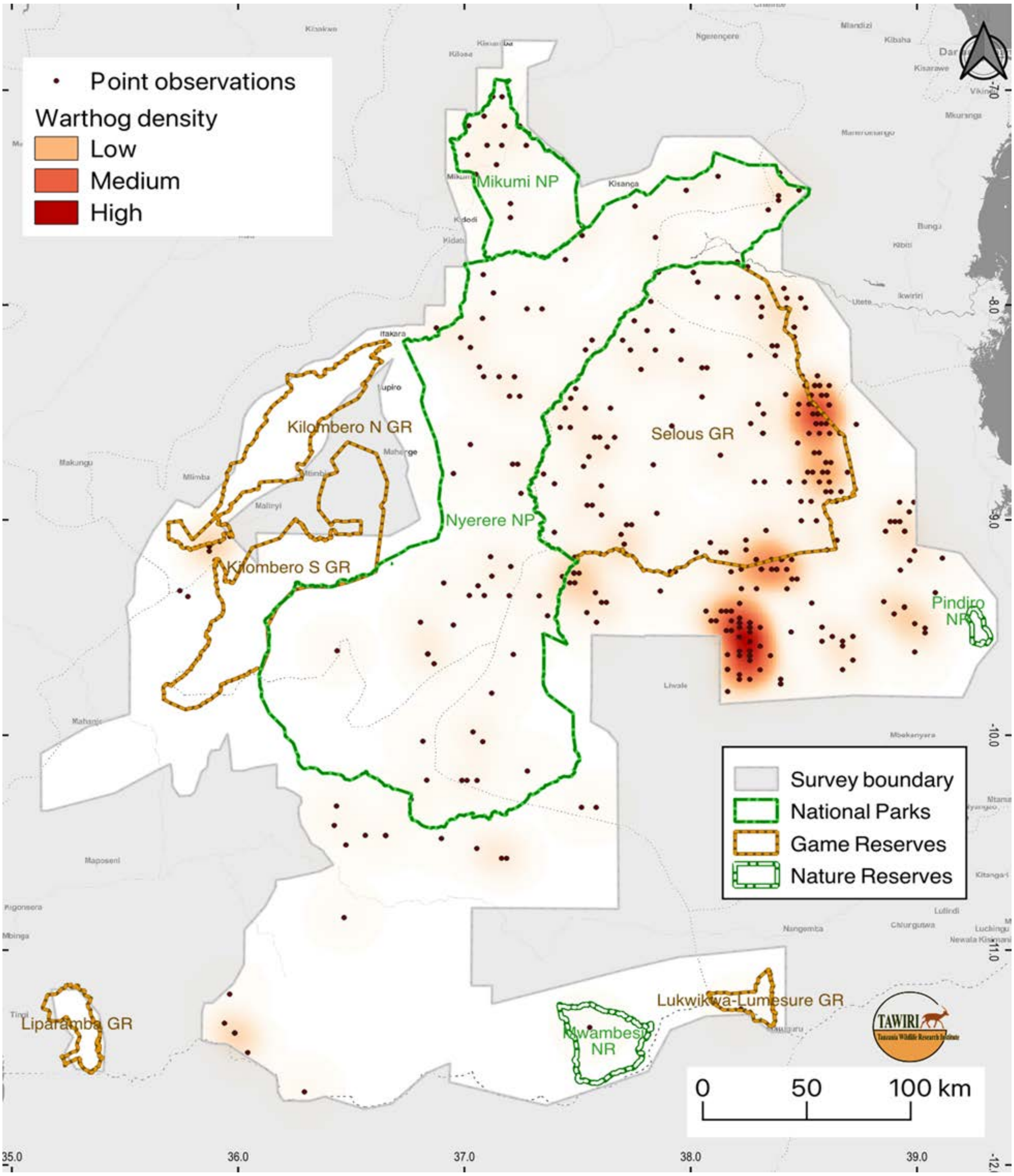


Figure 28: Dry season warthog distribution and density in the ecosystem in 2022

Warthogs were sparsely distributed in Nyerere NP and the northern side of the Selous-Niassa corridor, with only a few observations on the western side (Appendix 4). The long-term trend indicates a stable population after a decline recorded between 2002 and 2022 (Fig. 29). It should be noted, however, that warthogs were estimated to be around 20,000 in 1976.

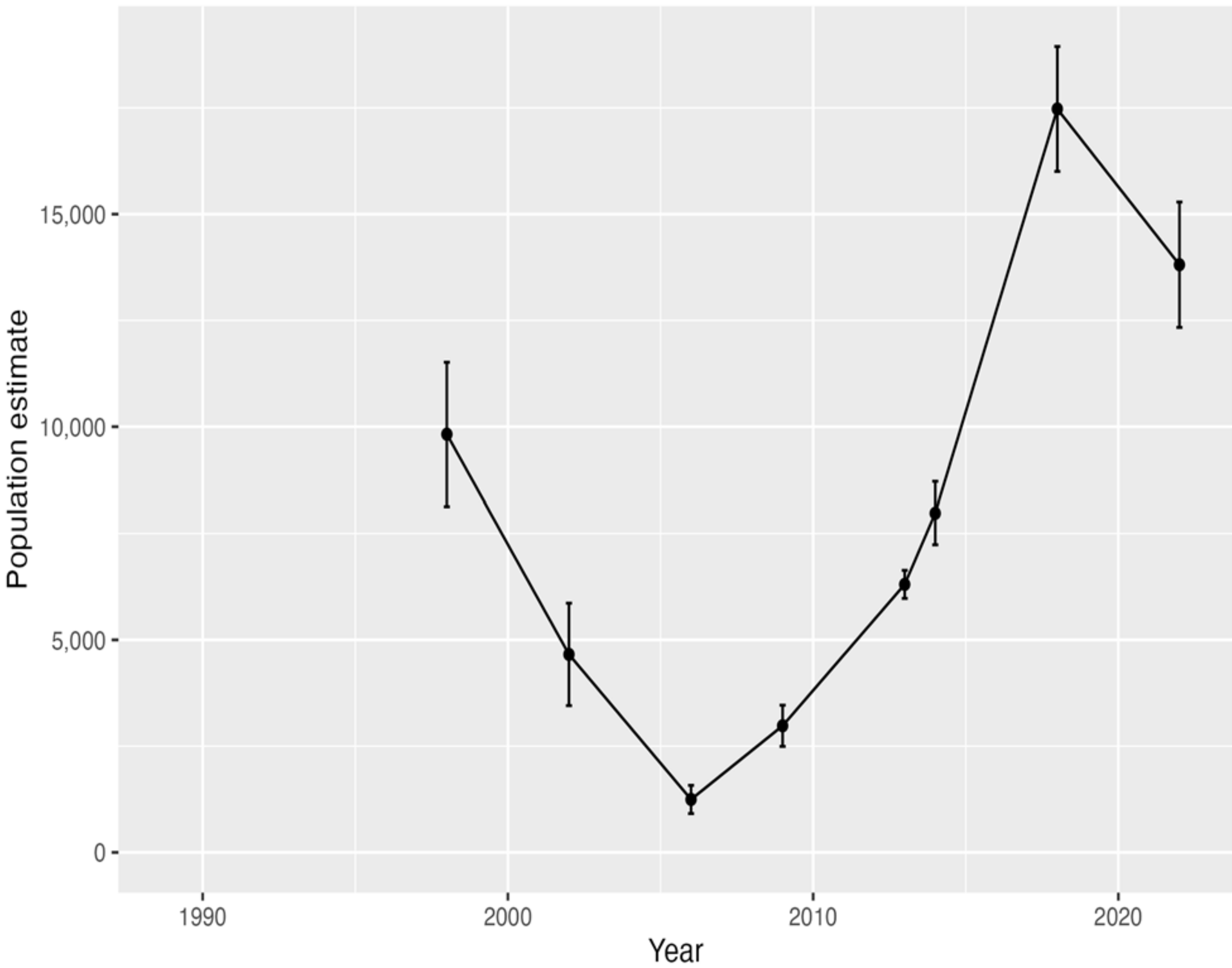


Figure 29: Warthog population trend in the ecosystem from 1994 to 2022 (vertical bars indicate SE)

3.3.14. Duiker distribution and density

Results indicate that a total of 16,758 ± 963 SE duikers were estimated in the ecosystem (Table 2). Of all counted species, duikers were among the most widely distributed species. The highest concentrations were observed outside southeast (Liwale) (6,256 ± 718 SE), followed by the Selous-Niassa wildlife corridor (3,360 ± 435 SE), Selous GR (2,497 ± 234 SE), Nyerere NP (2,183 ± 263 SE) (Appendix 4). The remaining part of the Selous GR showed a sparse distribution pattern and no observations were made in Kilombero GCA (GR) and in other parts (Fig.30).

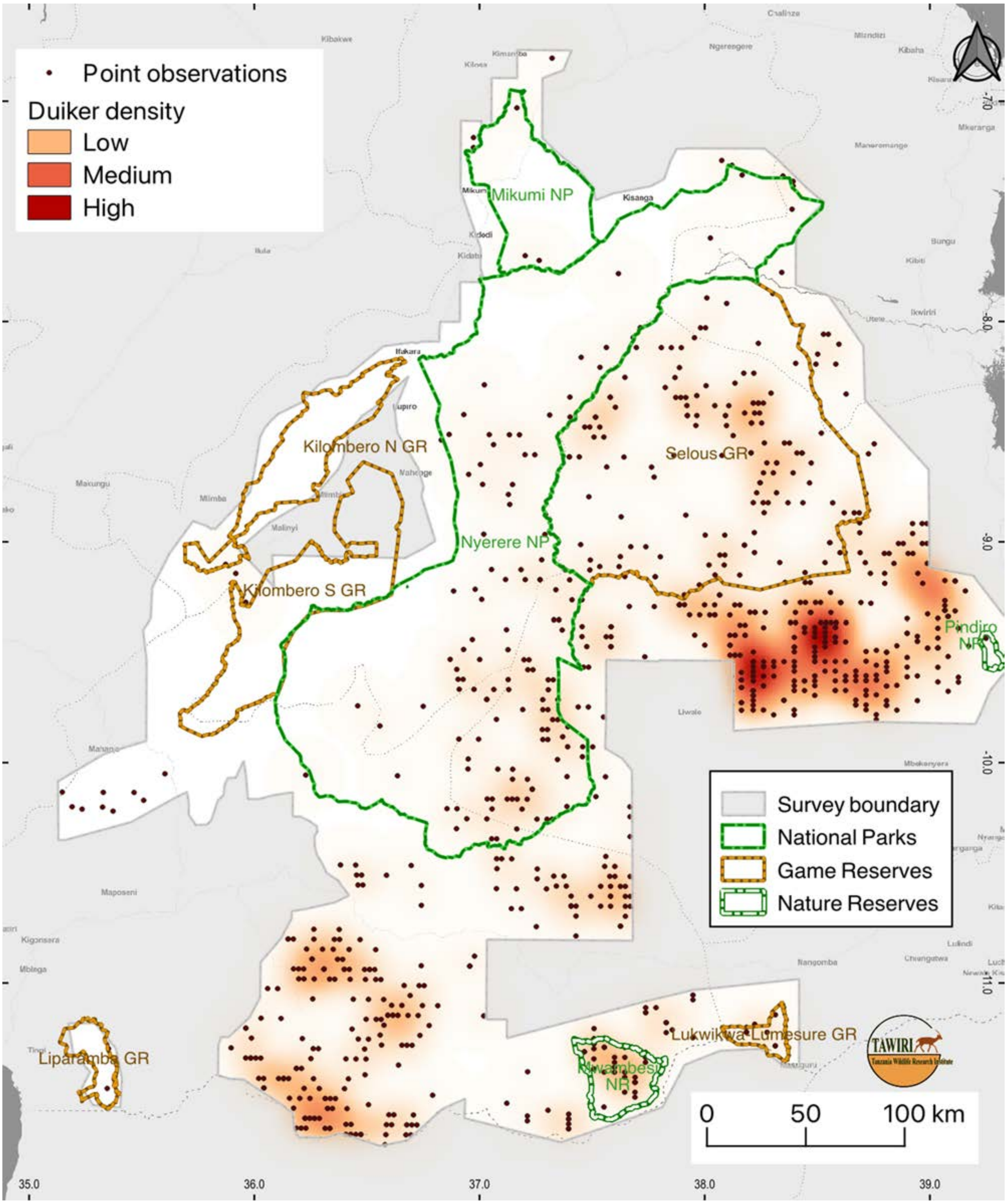


Figure 30: Dry season duiker distribution and density in the ecosystem in 2022

In Liwale, it was observed to be widely distributed with high concentrations at the central and southern parts. In Selous-Niassa, the highest concentration was in the central and southern parts, whereas in Nyerere NP, they were observed from the central throughout the southern and eastern parts. Mwambesi NR, as well as Lukwika-Lumesule, recorded the highest concentration. In Mikumi NP, very few were observed, as well as in the Gezamasoua Forest Reserve. Like warthogs, duikers indicate a population that has increased several-fold since 2006 (Fig. 31). A better understanding of these increments (duiker and warthogs) is recommended, especially as high concentrations occur in similar areas which may represent an ecological shift.

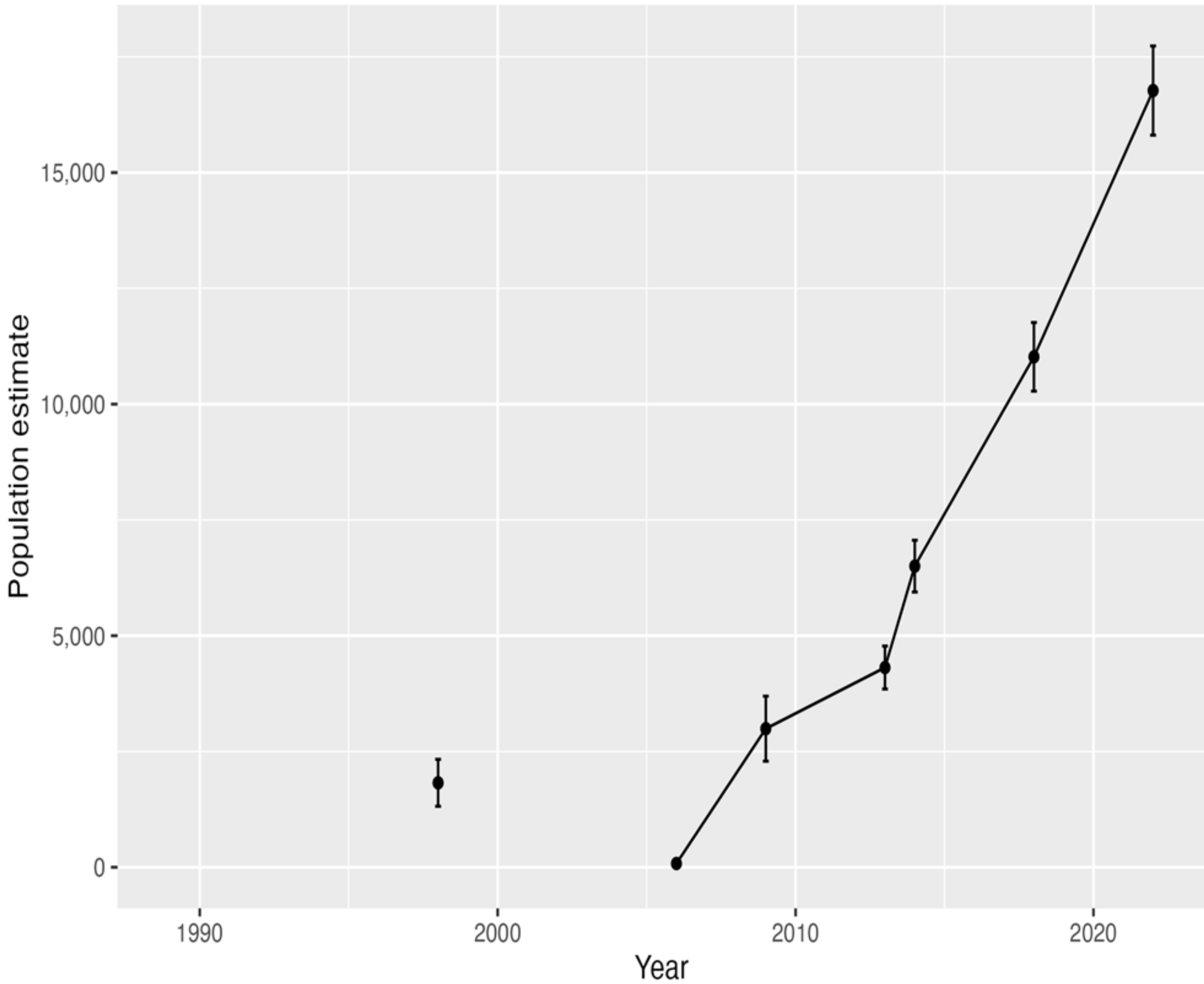


Figure 31: Duiker population trend in the ecosystem from 1994 to 2022 (vertical bars indicate SE)

3.3.15. Puku distribution and density

Historically, Tanzania was known to have two sub populations of puku, with Kilombero valley being the stronghold. However, in recent years, the species population has declined largely due to anthropogenic pressures. In this survey, puku were estimated at 496 ± 186 SE and recorded a restricted distribution in the ecosystem (Table 2). In contrast to recent censuses, the species was not only observed in the Kilombero GR, but also in small numbers in the western part of Nyerere NP and Selous GR. This distribution outside of Kilombero was also reported in 1976 by Douglas-Hamilton (Fig. 32).

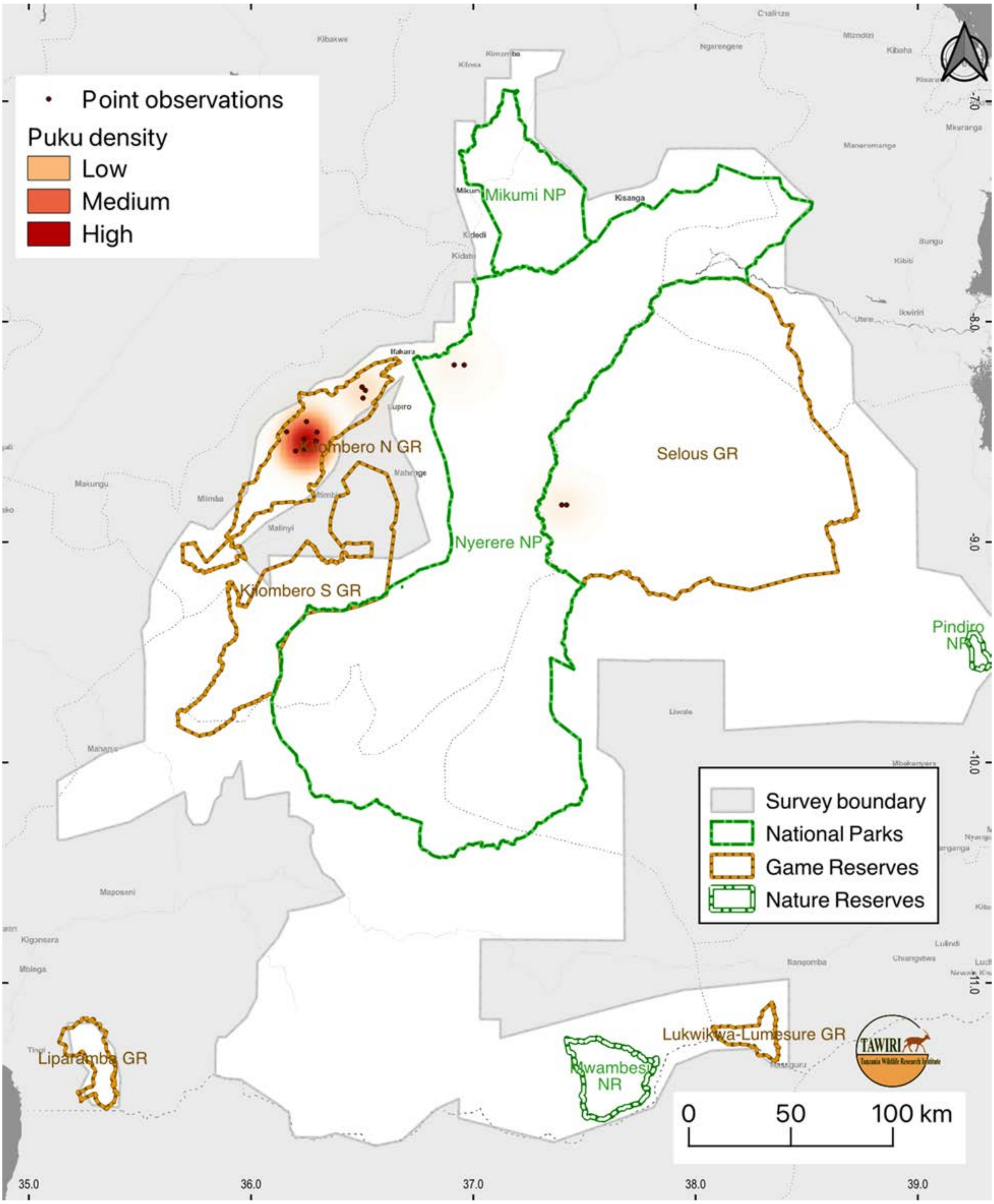


Figure 32: Dry season puku distribution and density in the ecosystem in 2022

Kilombero was once a stronghold of puku in Africa. The species is under major threat compared to all other species in the ecosystem, and its population has been declining from the country record of 50,000 individuals in the 1990s to 3000 in 2018 and 496 in 2022 (Fig.33). Clearly, the existence of this population is seriously threatened by the ever-increasing degradation of its habitat caused by human activities (Figs. 41,42,43,44).

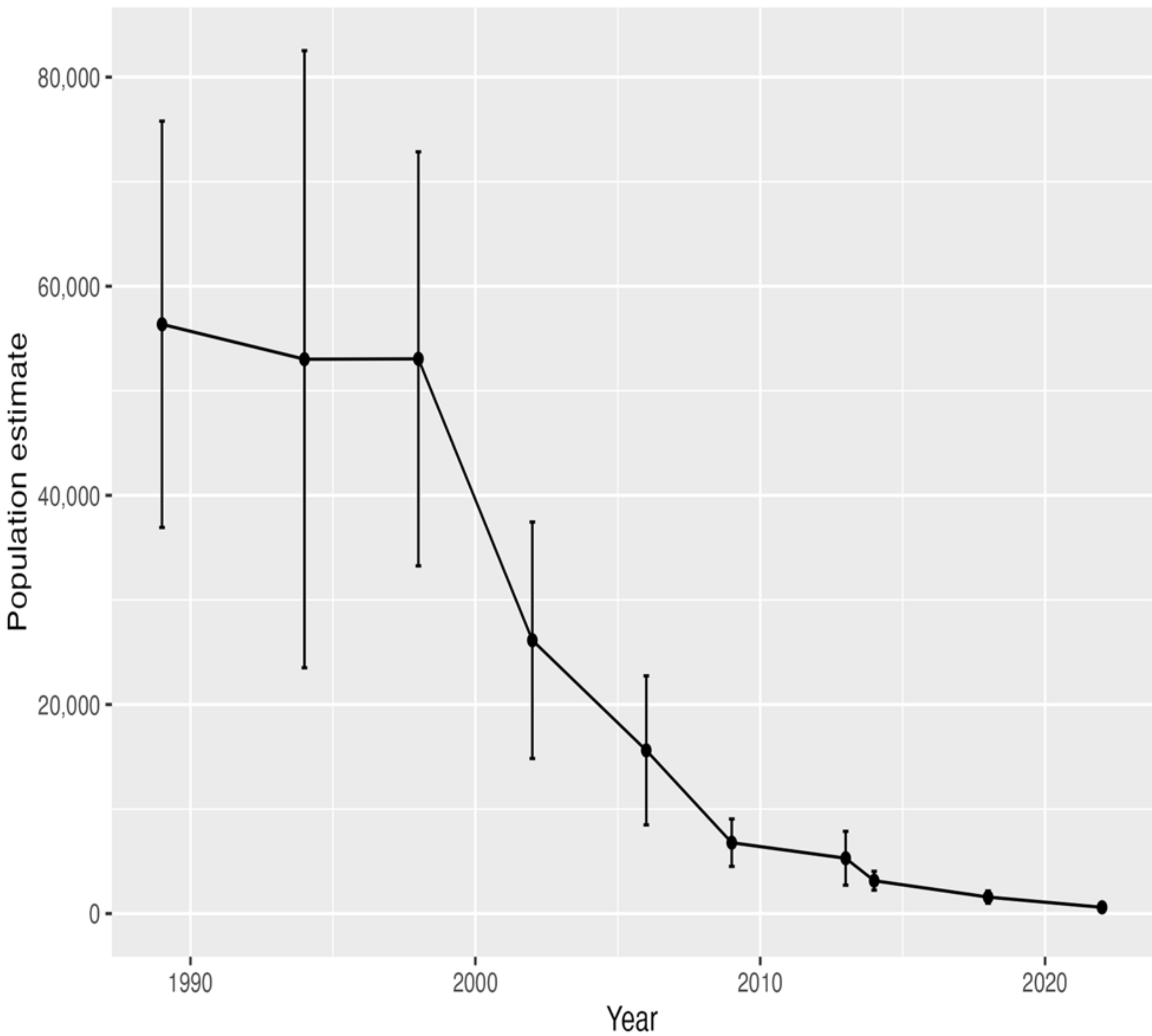


Figure 33: Puku population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

Urgent intervention by the authorities is strongly recommended to save this population before it becomes locally extinct.

3.3.16. Kudu distribution and density

Kudu was among the most sparsely distributed species in the ecosystem. The ecosystem population stands at 1,414 ± 333 SE (Table 2), and it exhibits the highest concentration in Outside South East (Liwale) (484 ± 203 SE), followed by Selous GR (440 ± 224 SE) and Nyerere NP (337 ± 107 SE) (Appendix 4). No observations were recorded in Kilombero GCA (GR), Masasi, Mikumi, Ngarambe-Tapika, Kidunda-Gonabis, and Mahenge (Appendix 4). The species shows the sparse Distribution over Liwale and Selous GR as well as in Matambwe, the central and southern part of the Nyerere NP (Fig. 34).

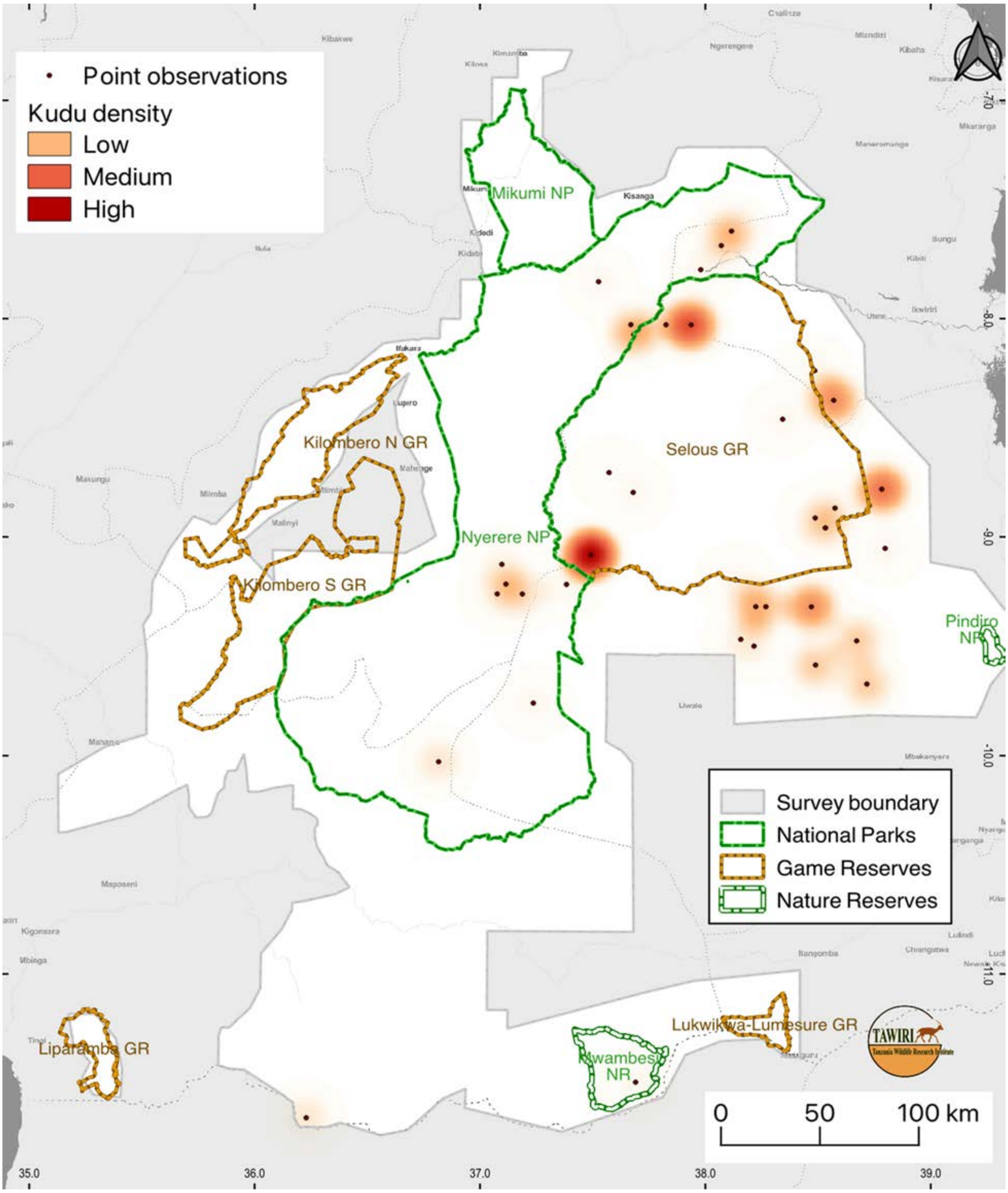


Figure 34: Dry season kudu distribution and density in the ecosystem in 2022

The sparse distribution of Greater kudu in the ecosystem accounts for the wide standard error attached to the population estimates consequently affecting the reliability of the estimates (Fig. 34). Nevertheless, the long-term trend suggests a stable population of about 1500 to 2000 individuals since the early 1990s (Fig. 35).

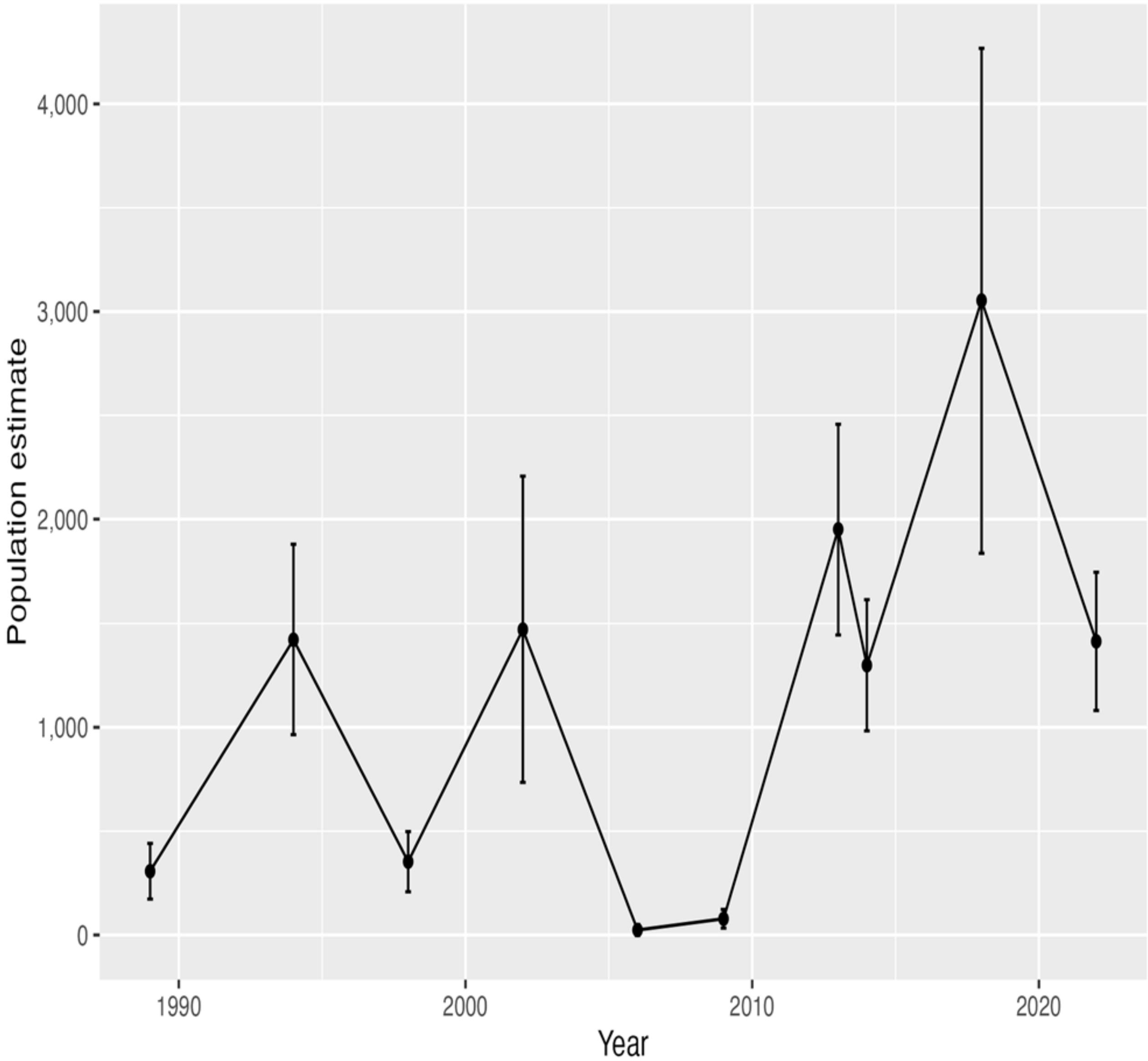


Figure 35: Kudu population trend in the ecosystem from 1989 to 2022 (vertical bars indicate SE)

3.3.17. Reedbuck distribution and density

The reedbuck population is estimated to be 2,197 ± 541 SE individuals (Table 2). Nyerere National Park (NP) exhibited the highest concentration of the species, with an estimated population of 958 ± 379 SE individuals, followed closely by Mikumi NP with an estimate of 482 ± 338 SE and Selous GR with an estimated population of 405 ± 161 SE individuals (Appendix 4). The distribution pattern of reedbuck within the ecosystem is characterized by sparsity, particularly in the central and southern parts of Nyerere NP and Selous GR, as well as in the Niassa corridor highlighting the specialized habitat requirements and ecological preferences of the species (Fig. 36).

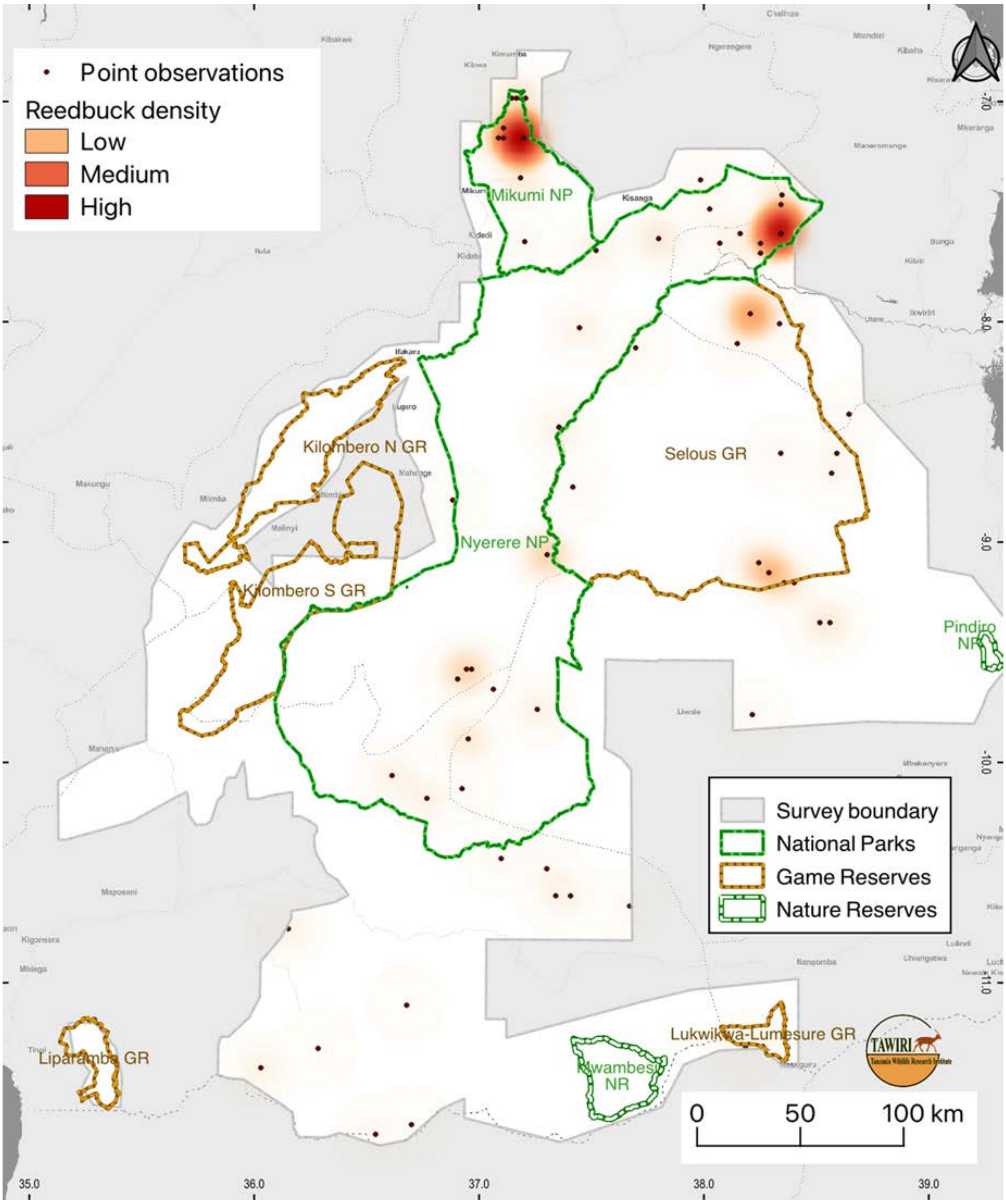


Figure 36: Dry season reedbuck distribution and density in the ecosystem in 2022

Reedbuck are adapted to specific habitats and are often associated with areas of suitable vegetation, such as grasslands, open woodlands, and savannahs. Consequently, their presence is limited to specific regions within the study area. Despite the sparse distribution and the associated challenges in observing and monitoring reedbuck populations, the short-term trend analysis indicates a stable population. This suggests that, within the current timeframe, there have been no significant fluctuations or noticeable declines in the reedbuck population (Fig. 37). However, it is important to note that the high standard errors associated with the population estimates reflect the inherent variability and uncertainty in the data collected. It is essential to continue long-term monitoring efforts to assess the persistence and conservation status of reedbuck populations in light of potential future ecological changes and anthropogenic pressures.

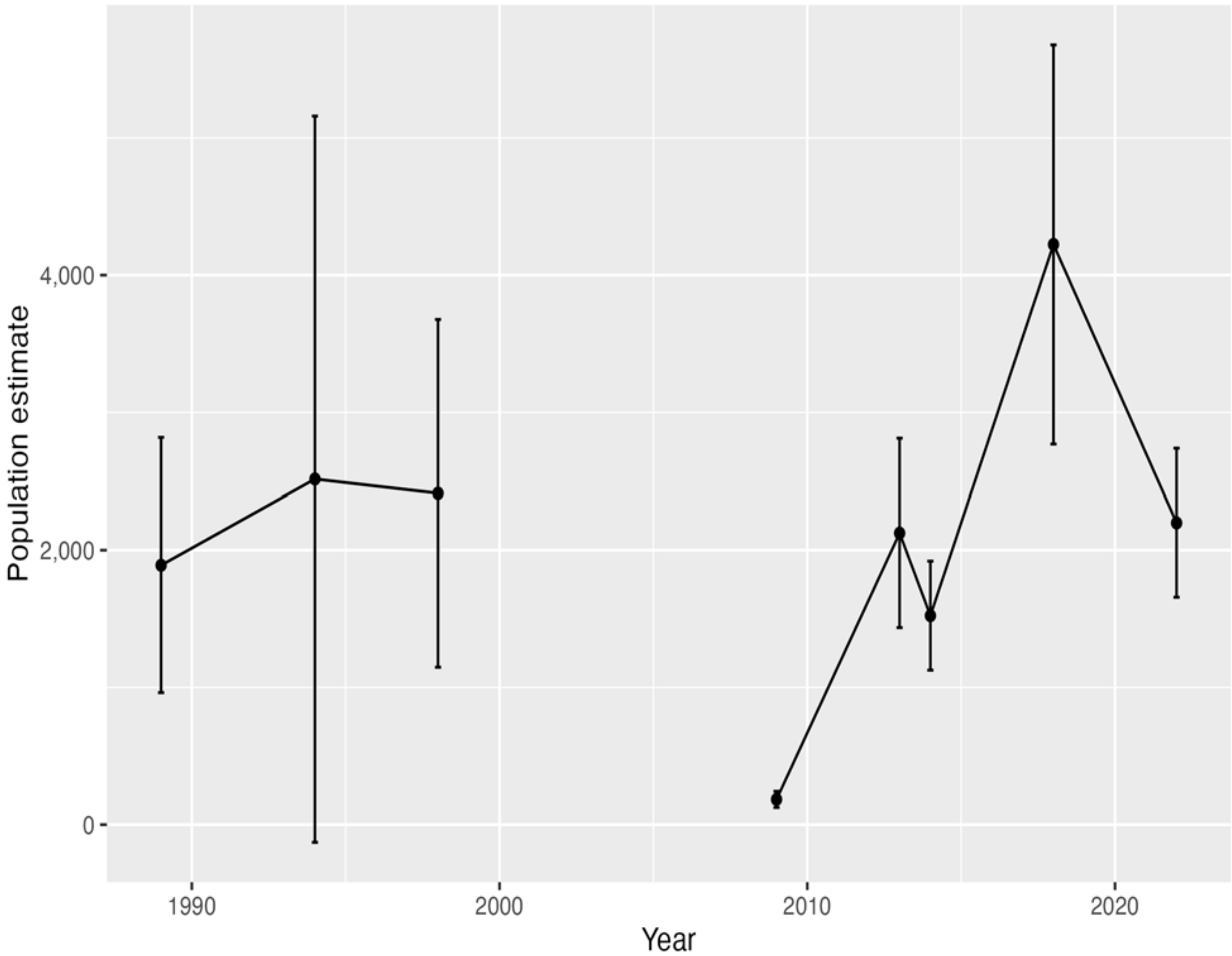


Figure 37:Reedbuck population trend in the ecosystem from 1989 to 2022(vertical bars indicate SE)

3.3.18. Large Avian species distribution

In addition to the mammalian populations, the ecosystem also supported some groups of large bird species that exhibited wide distribution patterns. Observations revealed that the southern part of Nyerere National Park recorded the highest number of avian species compared to the northern part suggesting a variation in habitat suitability and ecological factors influencing the presence and abundance of avian communities within the park. Selous Game Reserve, along with the areas outside the reserve including Liwale, exhibited a broader distribution of avian species indicating the presence of suitable habitats and ecological niches supporting diverse bird populations in these areas. The presence of avian species highlights its ecological importance as a connecting pathway for bird populations between different habitats. However, it is worth noting that there were no avian records in Kilombero Game Controlled Area (GCA), Mahenge, and Mbalika.

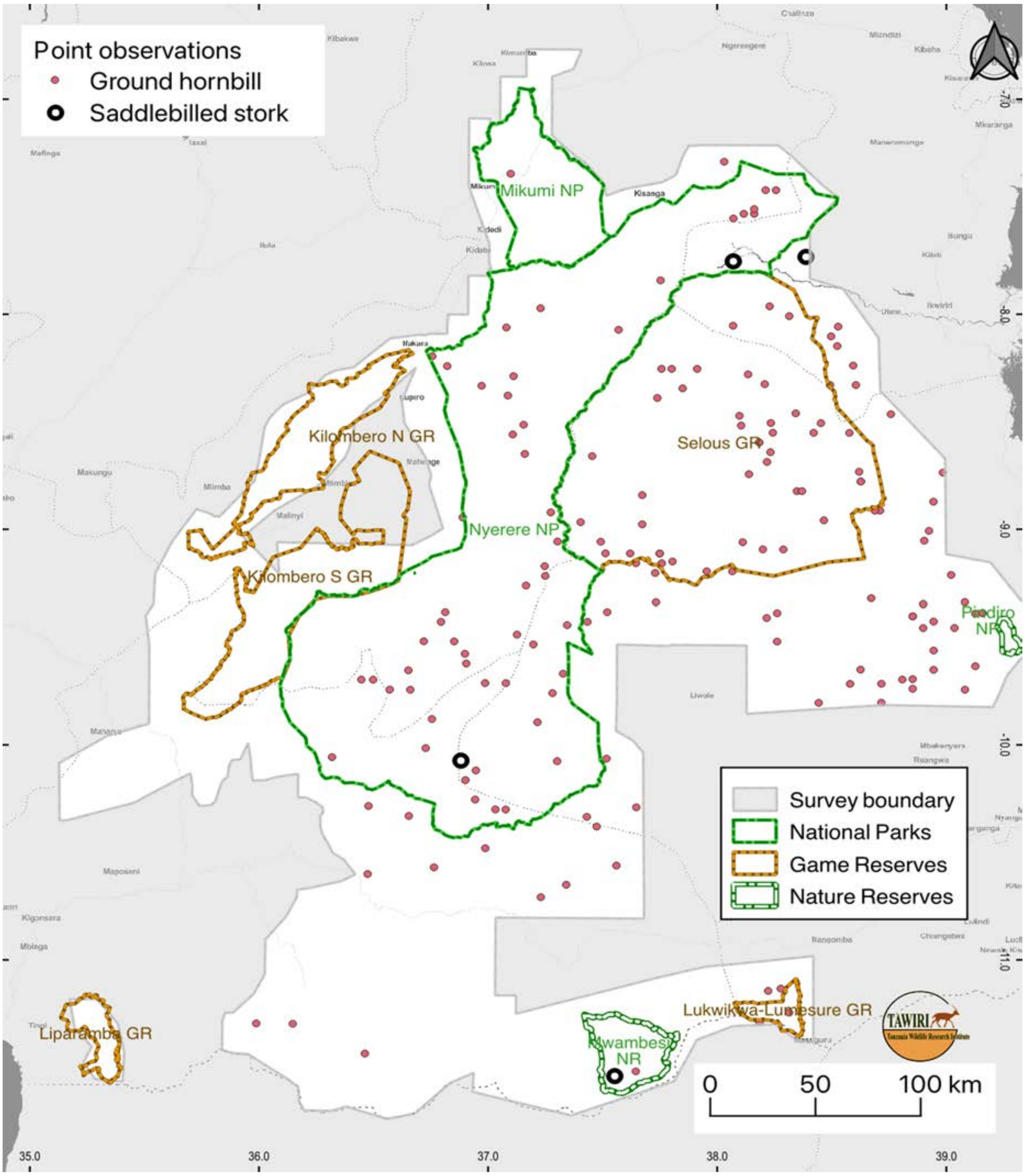


Figure 38: Distribution of large avian species in the ecosystem in the dry season in 2022

This absence of avian observations in these areas could be attributed to various factors such as differences in habitat composition, ecological conditions, or limited survey efforts. Further research and monitoring are required to better understand the avian distributions in these specific areas and to assess the potential factors influencing their absence (Fig. 38). The wide distribution of large bird species within the ecosystem underscores the importance of maintaining diverse habitats and ecological corridors to support their populations. Avian communities play crucial roles in ecosystem functioning, including pollination, seed dispersal, and insect control. Therefore, conservation efforts should consider the protection and preservation of suitable habitats for avian species, as their presence contributes to the overall biodiversity and ecological balance of the ecosystem.

3.3.19. Human activity estimates, distribution and trends

The Nyerere-Selous-Mikumi Ecosystem exhibited a range of observed human activities, with a total of fifteen distinct activities documented (Figs. 39,40,41,42,43,44; Appendix 4). Among these activities, livestock rearing was the most abundant (Fig. 39). The estimated population of cattle in the ecosystem was 802,089 ± 41,997 SE individuals, indicating a high presence of cattle within the study area. The next most prevalent human activities were related to shoats (such as sheep and goats) with an estimated population of 179,473 ± 17,448 SE individuals. Occupied bomas, which are traditional livestock enclosures, were also frequently observed, with an estimated count of 23,055 ± 4,520 SE structures. Thatched huts, likely serving as human dwellings, were documented as well, with an estimated count of 16,860 ± 2,558 SE structures. In contrast, certain human activities were less commonly observed within the ecosystem. Fishing camps, where fishing activities take place, exhibited a relatively low presence, with an estimated count of 1,849 ± 269 SE camps. Similarly, charcoal kilns used for charcoal production and canoes used for transportation on waterways were less frequently documented, both with estimated counts of 1,583 ± 579 SE and 1,849 ± 269 SE, respectively. Additionally, human activities such as cultivation, tree felling, and poachers' camps were observed but had too few instances to calculate reliable estimates (Appendix 4). These documented human activities provide insights into the interactions between human populations and the Nyerere-Selous-Mikumi Ecosystem. The high abundance of livestock, particularly cattle and shoats, suggests the significant influence of pastoralism on the landscape. The presence of occupied bomas and thatched huts further indicates the presence of local communities residing within or near the ecosystem. Understanding and monitoring these human activities is essential for assessing their potential impacts on the ecosystem, including habitat degradation, biodiversity loss, and conflicts between wildlife and human populations. Effective management and conservation strategies should consider the sustainable utilization of resources, promotion of alternative livelihood options, and the mitigation of potential negative consequences associated with these human activities.

3.3.19.1. Cattle estimates

The distribution of cattle populations within the Nyerere-Selous-Mikumi Ecosystem reveals significant variations across specific areas (Fig. 39). Kilombero GCA (GR) stands out with the highest estimated count of cattle, numbering 261,512 ± 15,600 SE individuals, followed by Liwale with 195,020 ± 25,815 SE individuals , Kidunda-Gonabis with 105,979 ± 17,761 SE individuals , and Out Mikumi with 54,203 ± 11,335 SE individuals. In contrast, the Selous GR exhibits the lowest estimated count of cattle, totaling 4,186 ± 2,816 SE individuals (Appendix 4). It is noteworthy that certain areas within the ecosystem, namely Mwambesi GR, Mikumi NP, and Lukwika-Lumesule GR, had no recorded observations of cattle (Appendix 4 & Fig. 39). This absence of cattle sightings could be attributed to various factors, such as distinct land use practices, management strategies, or limited survey efforts targeting those specific areas.

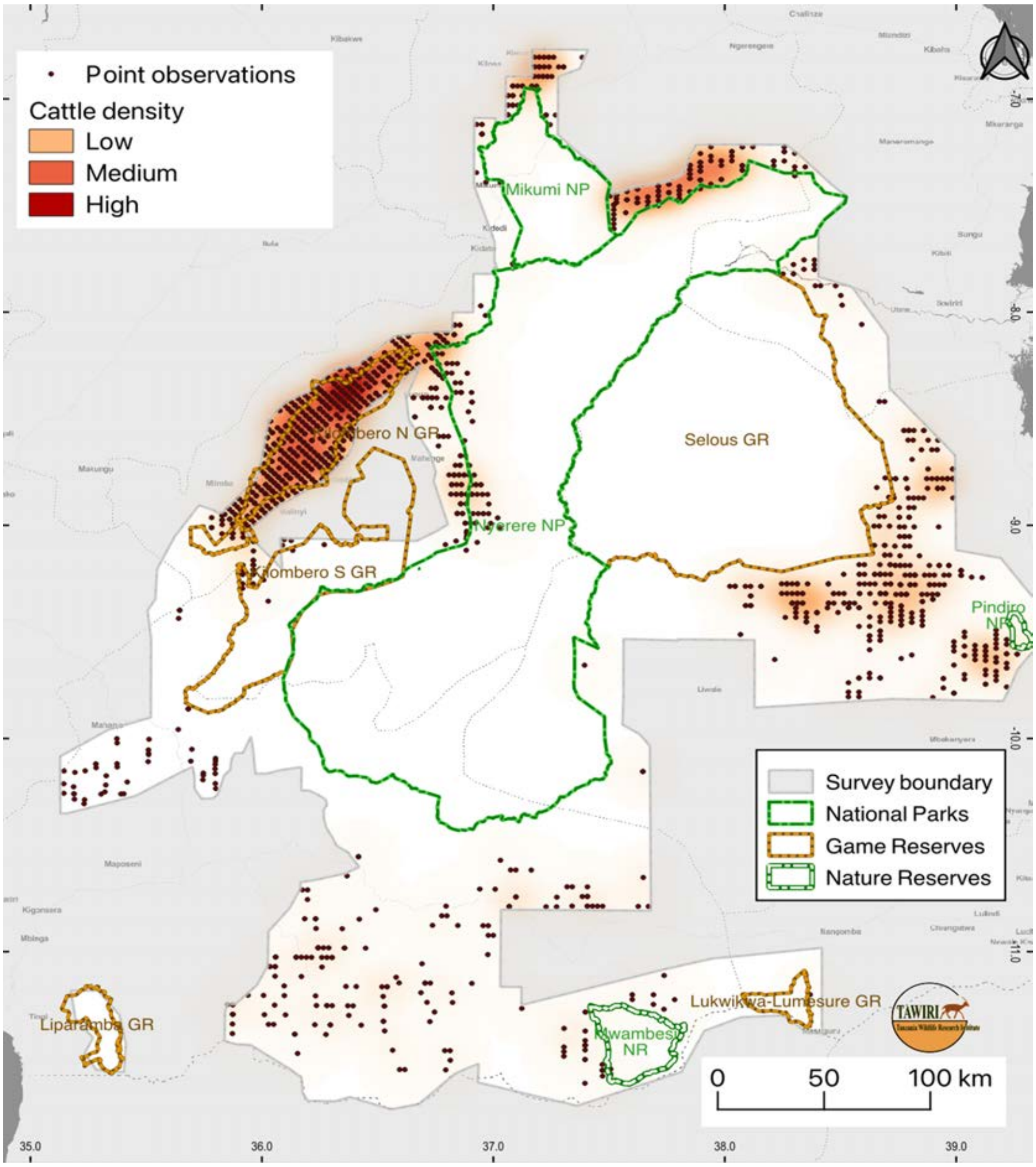


Figure 39: Distribution and density of cattle in dry season in 2022

The distribution patterns of cattle within the ecosystem displays clear trends indicating wide distributed throughout the Kilombero GCA (GR), extending from the eastern part of Selous GR and reaching downwards towards Liwale. Conversely, the highest concentration of cattle is observed in the Kidunda-Gonabis area (Fig. 39).

In general, these distribution patterns reflect variations in human settlement patterns, grazing practices, and land availability across different regions within the ecosystem. Understanding the spatial distribution of cattle populations is crucial for effective ecosystem management and conservation planning. It provides valuable insights into the intricate interactions between human activities and wildlife habitats, as well as the potential conflicts and ecological impacts associated with livestock-rearing practices. The variations in cattle populations among different administrative blocks emphasize the significance of considering area-specific differences and implementing tailored management strategies to ensure sustainable livestock practices within the Selous-Mikumi ecosystem. By taking these variations into account, conservationists and policymakers can develop targeted measures that address the unique challenges and opportunities presented by each area, promoting the long-term sustainability of both livestock and the ecosystem as a whole.

3.3.19.2. Shoats estimates

The distribution of shoats (young sheep and goats) within the Nyerere-Selous-Mikumi Ecosystem exhibited distinct patterns (Fig. 40). The highest numbers of shoats were observed in specific areas, with the Kilombero GCA (GR) recording the highest count of 50,594 ± 7,836 SE individuals, followed by Liwale with 48,168 ± 8,969 SE individuals and Kidunda-Gonabis with 31,172 ± 9,421 SE individuals (Appendix 4). Certain PAs namely Lukwika-Lumesule GR, Mwambesi NR, and Mikumi NP had no recorded observations of shoats (Appendix 4 & Fig. 40). The absence of shoat sightings in these areas could be attributed to various factors, including differing habitat suitability, management practices, or limited survey efforts targeting those specific regions. Spatially, shoats were found across various locations within the ecosystem namely throughout the Kilombero GCA (GR), Kidunda-Gonabis, Out Mikumi, and the central and northern parts of Liwale (Fig. 40).

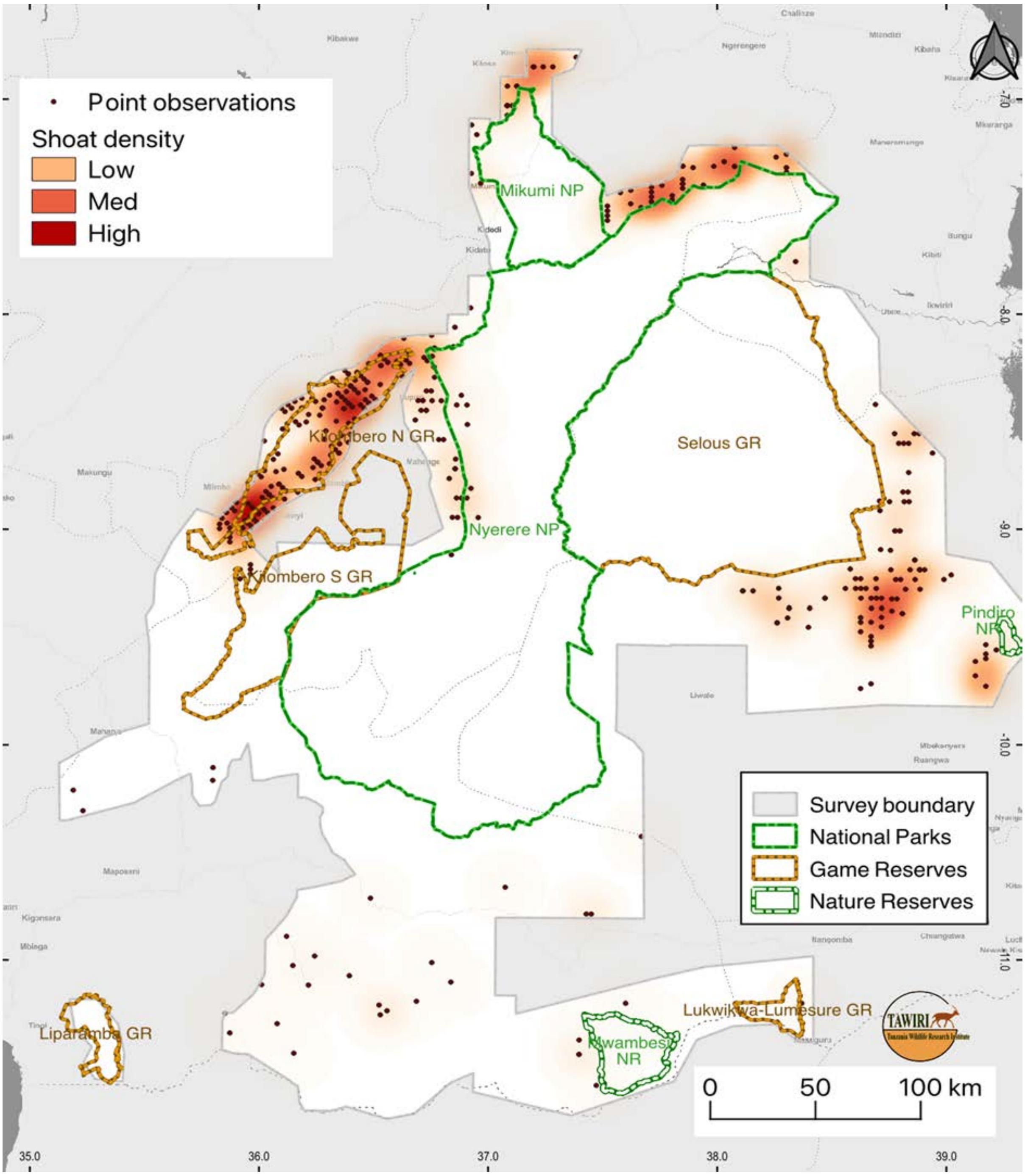


Figure 40: Distribution and density of shoats in the dry season in 2022

These distribution patterns reflect variations in grazing opportunities, vegetation availability, and human activities across different regions within the ecosystem. Like Cattles, understanding the spatial distribution of shoat populations is essential for effective management and conservation planning. It provides valuable insights into the areas that support higher shoat numbers and the regions where they are absent. This knowledge can inform decisions regarding grazing management, habitat conservation, and potential conflicts between livestock-rearing and wildlife conservation. The variations in shoat populations among different areas underscore the importance of considering specific ecological and management factors when implementing sustainable livestock practices. By recognizing the spatial distribution patterns and adapting management strategies accordingly, stakeholders can ensure the long-term viability of shoat populations and the overall ecological integrity of the Nyerere-Selous-Mikumi Ecosystem.

3.3.19.3. Settlement estimates

In the context of this report, the term "settlement" refers to different types of human dwellings, including thatched houses, mabati houses (houses made of corrugated metal sheets), and villages consisting of multiple houses in one location. These settlements were observed extensively throughout the study area, with notable concentrations in the Selous-Niassa corridor, Liwale, and the Kilombero GCA (GR) (Fig. 41). Thatched huts, in particular, were numerous in the Selous-Niassa corridor, with an estimated count of 28,588 ± 2,979 SE units , followed by Liwale with 23,627 ± 3,982 SE units and the Kilombero GCA (GR) with 19,098 ± 1,643 SE units (Appendix 4). The distribution of these settlements reflects the patterns of human habitation and population density within the ecosystem. The Selous-Niassa corridor, which serves as a vital link between the Selous GR and the Niassa GR in neighbouring Mozambique, exhibited a significant presence of thatched huts. This is likely due to the proximity to protected areas and the presence of local communities relying on natural resources for their livelihoods. Liwale, located in the southern part of the ecosystem, also showed a considerable number of thatched huts, indicating the presence of settled communities in the area. Additionally, the Kilombero GCA (GR), which encompasses a diverse range of habitats, supported a substantial number of thatched huts.

Understanding the spatial distribution of human settlements is crucial for comprehensive ecosystem management and conservation planning. It allows for the identification of areas with higher human-wildlife interactions and potential conflicts. Moreover, recognizing the distribution of settlements provides insights into the socio-economic dynamics, land-use patterns, and potential impacts on the ecosystem. By considering the distribution and density of settlements, policymakers and conservationists can develop targeted strategies to mitigate human-wildlife conflicts, promote sustainable land-use practices, and foster coexistence between human communities and wildlife populations. It is imperative to balance the needs of local communities with the conservation objectives to ensure the long-term ecological integrity and socio-economic well-being within the Nyerere-Selous-Mikumi Ecosystem.

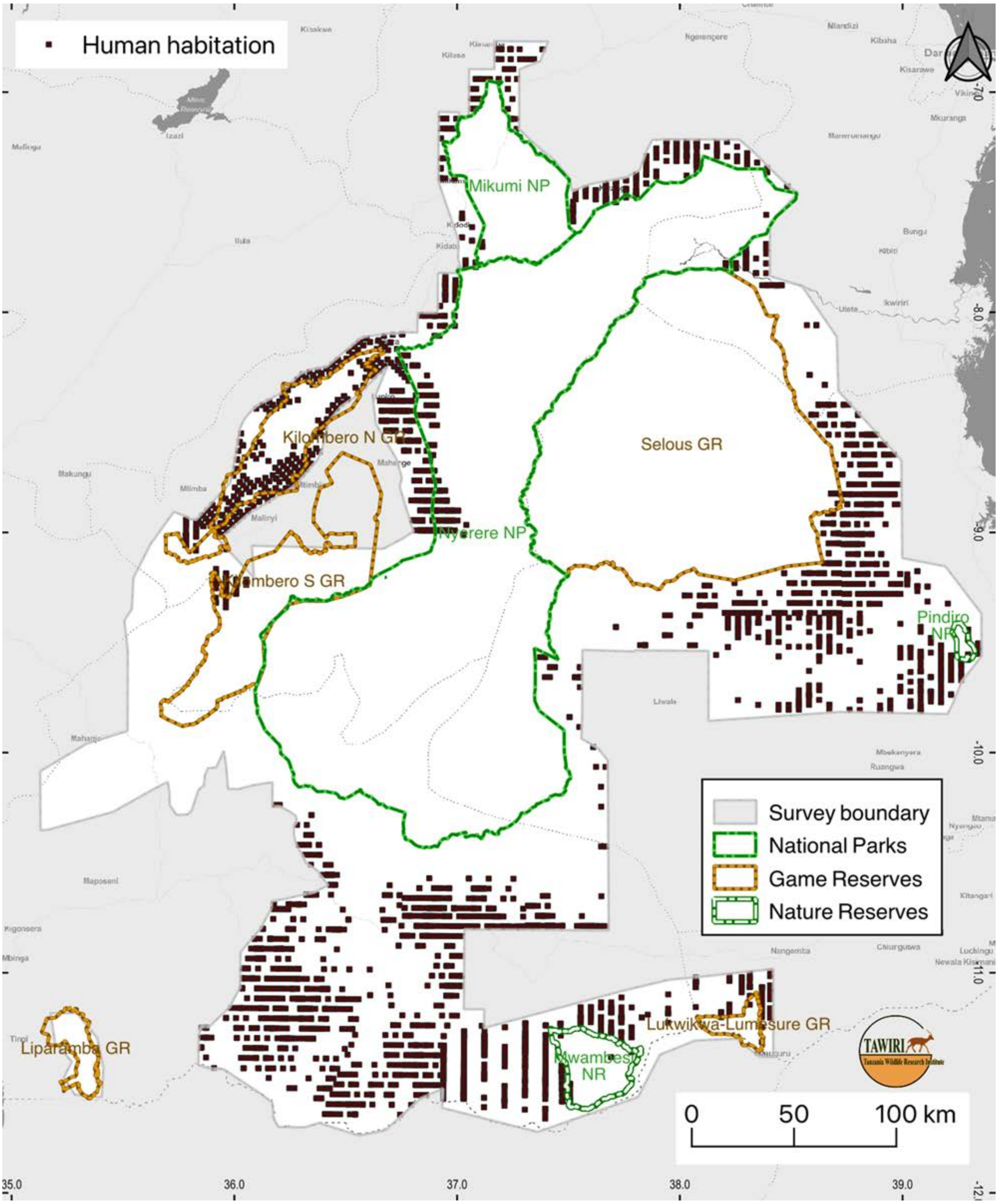


Figure 41: Distribution and density of settlement in the dry season 2022

3.3.19.4. Tree-Felling

The distribution pattern of tree-felling activities within the Nyerere-Selous-Mikumi Ecosystem revealed notable concentrations in specific areas. Liwale exhibited the highest concentration of tree-felling, with an estimated count of 14,646 ± 5,482 SE, followed by Nyerere NP with 1,774 ± 1,571 SE (Appendix 4). Spatially, the areas with significant tree-felling activities extended from the northern area to the southern boundary of the Selous GR, predominantly concentrated in the eastern part of Liwale. Moreover, high concentrations of tree-felling were observed in the Selous-Niassa corridor and the Mahenge area. Conversely, tree-felling activities showed a sparse distribution in other areas within the ecosystem (Fig. 42). The distribution patterns of tree-felling reflect the complex interplay between human activities and the availability of forest resources within the Nyerere-Selous-Mikumi Ecosystem. Liwale, characterized by a higher concentration of tree-felling, likely represents areas where the demand for forest resources, such as timber and firewood, is relatively high. This can be attributed to factors such as population density, economic activities, and local livelihood practices that rely on forest resources. The concentration of tree-felling activities in the Selous-Niassa corridor and the Mahenge area may be influenced by the proximity to natural resource-rich areas, the presence of local communities, and historical patterns of land use. These areas may serve as important hubs for timber extraction or other forest-related activities due to their accessibility and resource availability.

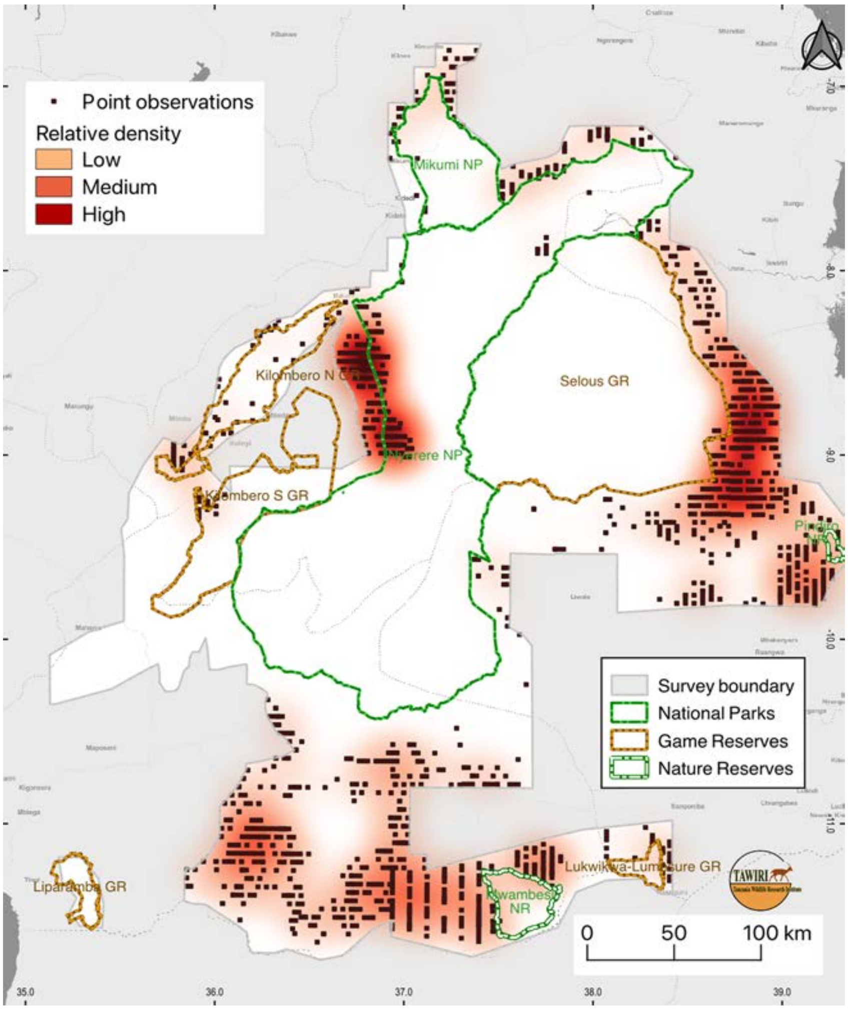


Figure 42: Distribution and density of tree felling in the dry season in 2022

Understanding the spatial distribution of tree-felling activities is crucial for effective natural resource management, conservation planning, and sustainable development within the Nyerere-Selous-Mikumi Ecosystem. It provides valuable insights into areas of high human impact on forest resources, potential ecological consequences, and the need for targeted interventions to promote sustainable forestry practices.

Efforts to mitigate the negative impacts of tree-felling should consider socio-economic factors, community engagement, and alternative livelihood options to address the underlying drivers of deforestation and forest degradation. By promoting sustainable forestry practices, conservationists and policymakers can work towards preserving the integrity of the ecosystem, safeguarding biodiversity, and maintaining the vital ecosystem services provided by forests.

3.3.19.5. Saw-pits

Sawpits, which are indicative of tree-felling activities, displayed a wide distribution outside the protected areas within the Nyerere-Selous-Mikumi Ecosystem. The administrative analysis revealed that sawpits were concentrated in specific areas, aligning with the spatial distribution of tree felling (Fig.43). The highest concentrations of sawpits were observed in the outside-east (Ngarambe-Tapika), outside southeast (Liwale), outside-west (Mbalika), and the northeastern part of Selous GR (Appendix 4). These areas exhibited notably high densities of sawpits, with some locations recording extremely high concentrations. Conversely, relatively low-density areas of sawpits were identified in the Selous-Niassa corridor, outside Mikumi west (Kidunda-Gonabis), and Lukwika-Lumesule GR (Fig. 43). These areas showed fewer instances of sawpits, suggesting lower levels of tree-felling activities in those specific areas. The administrative distribution of sawpits outside the protected areas provides insights into the spatial patterns of tree-felling and the associated human activities. The concentrations of sawpits in particular areas indicate areas where the demand for timber extraction is relatively high, potentially driven by economic activities, population density, and proximity to forest resources.

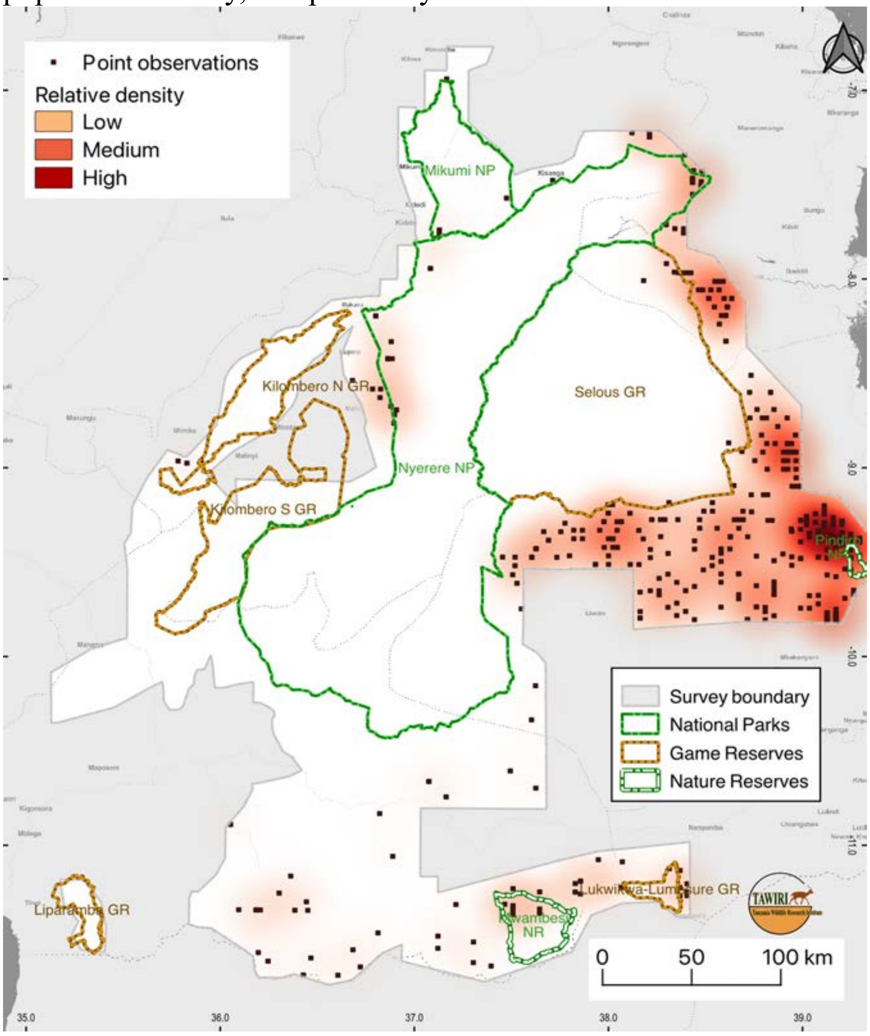


Figure 43: Sawpits distribution and density in dry season in 2022

Understanding the distribution of sawpits and the corresponding tree-felling activities is essential for effective natural resource management and conservation planning. It highlights areas of significant human impact on forest resources, potential ecological consequences, and the need for targeted interventions to promote sustainable forestry practices. Efforts to address the high concentrations of sawpits should consider implementing appropriate regulations, enforcement mechanisms, and community engagement strategies. By promoting sustainable forestry practices, stakeholders can work towards mitigating the negative impacts of tree felling, conserving the ecosystem's integrity, and ensuring the long-term sustainability of forest resources within the Nyerere-Selous-Mikumi Ecosystem.

3.3.19.6. Cultivation

Cultivation and fallow land, two significant indicators of human agricultural activities, exhibited extensive distribution throughout the Nyerere-Selous-Mikumi ecosystem. The analysis revealed that these activities were particularly concentrated in several areas, including Selous-Niassa, Masasi, Liwale, Kilombero GCA (GR), and outside Mikumi NP, with the eastern side of Selous GR displaying the highest concentrations (Appendix 4, Fig. 44). These areas experienced substantial levels of cultivation and fallow land, indicating the intensive use of land for agricultural purposes. In contrast, relatively low densities of cultivation were observed in the southern end of Nyerere NP (outside), suggesting less prevalent agricultural activities in that specific area. Furthermore, no observations of cultivation were recorded in Mikumi NP and Selous GR, signifying the absence or limited presence of agricultural practices in those protected areas. Only a few instances of cultivation were observed in Nyerere NP (Fig. 44), indicating relatively minimal human agricultural impact within the park boundaries. The wide distribution of cultivation and fallow land across the ecosystem, particularly in specific areas, underscores the significant role of agriculture in shaping the landscape and human activities within the Nyerere-Selous-Mikumi ecosystem. These patterns reflect variations in land use practices, agricultural traditions, soil fertility, and accessibility to water resources across different administrative units.

Understanding the spatial distribution of cultivation and fallow land is crucial for effective land management, sustainable agriculture, and conservation planning within the ecosystem. It provides valuable insights into the interactions between human activities and natural habitats, identifies areas of potential conflict between agriculture and wildlife conservation, and highlights the need for implementing appropriate land-use policies and practices to ensure the long-term ecological sustainability of the Nyerere-Selous-Mikumi ecosystem.

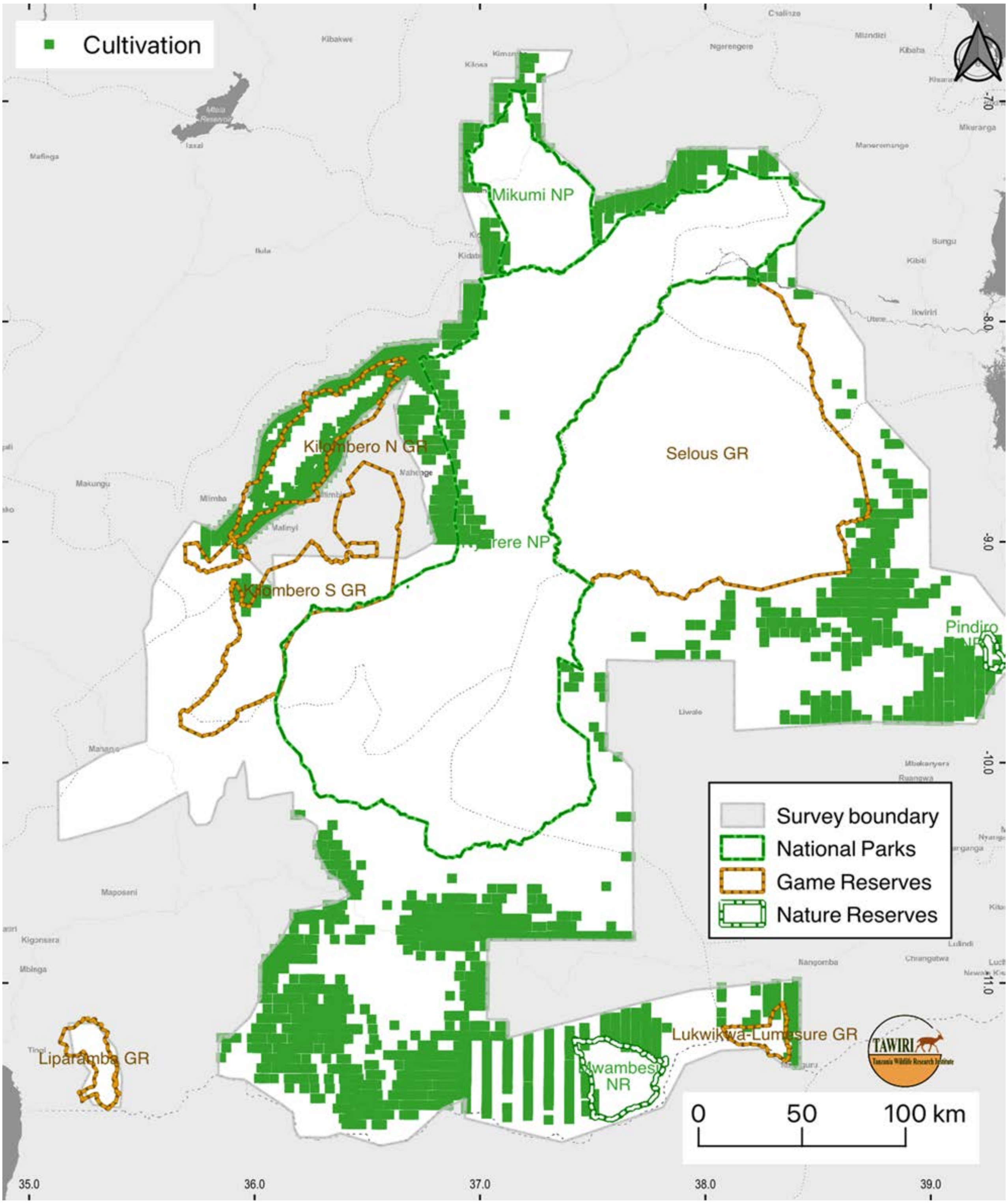


Figure 44: Cultivation distribution and density in the dry season of 2022

Generally, human activities pose significant threats to wildlife conservation within the ecosystem, leading to hindered ecological connectivity, habitat loss, and the creation of hard edges in protected areas. The expansion of livestock, establishment of poacher camps, and presence of sawpits have resulted in substantial habitat conversion, particularly in the wildlife-rich Masasi OA. The increasing livestock population poses a major threat to wildlife conservation, as exemplified in the Kilombero Valley, where a large buffalo herd has vanished from the core range within the Game Controlled Area. To prevent the local extinction of important species, concerted efforts are needed to preserve wildlife habitats in the Kilombero GCA (GR).

Table 4: A comparison of human activity trends in the ecosystem between 2018 and 2022

Year of Survey	**2018**		**2022**		***d-test***
Surveyed Area	**105,730 km²**		**101,537 km²**		
Human activity	**Estimates**	**SE**	**Estimates**	**SE**	
Cattle	678,303	73,205	799,411	41,997	*0.11552*
Shoats	171,893	27,304	179,330	17,448	*0.02994*
Poacher's camps	112	52	312	83	*0.60364*
Sawpits	9,015	772	15,657	4,633	*0.36763*
Hut with mabati roof	13,622	5,566	16,813	4,520	*0.14747*
Boma occupied	4,847	1,558	23,034	8,611	*0.77265*
Canoe	2,523	753	1,849	269	*-0.21546*
Boma - unoccupied	1,981	951	4,476	531	*0.50973*

The connectivity of wildlife between Tanzania and Mozambique through the Selous-Niassa corridor is at risk due to the ongoing unchecked expansion of human activities. Despite the presence of several WMAs within the corridor, the uncontrolled spread of human activities necessitates a review of the management modalities for these areas. Scientific research by Kideghesho (2015) supports the importance of wildlife corridors in facilitating gene flow, reducing inbreeding, and safeguarding endangered wildlife populations. The impact of hard edges is increasingly recognized as a major threat to wildlife conservation. Unlike the Serengeti-Mara ecosystem, where hard edges have already impeded the movement of migratory species, the Nyerere-Selous-Mikumi Ecosystem still has the opportunity to develop and implement effective strategies to mitigate the negative effects of hard edges. Improved planning and management are crucial for ensuring better ecological functioning within the ecosystem. Overall, addressing these challenges requires proactive measures to mitigate the adverse impacts of human activities, preserve ecological connectivity through wildlife corridors, and effectively manage protected areas and their boundaries.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

The conservation efforts of both the Tanzania National Parks Authority (TANAPA) and the Tanzania Wildlife Management Authority (TAWA) in safeguarding biodiversity within their respective jurisdictions in the ecosystem are highly commendable. The nearly absent carcass ratio observed in the ecosystem indicates that recent interventions by these institutions to combat illegal hunting have yielded positive outcomes. However, despite the stability of the population of most large mammal species in recent years, long-term trends suggest an overall decline, emphasizing the need for continued and intensified efforts to restore populations to their historical levels.

A matter of significant concern is the substantial decrease in the puku population within the Kilombero Game Reserve. This alarming decline necessitates collaborative endeavours from the responsible management authority to prevent the local extinction of this species. Furthermore, the escalating human activities occurring within the ecosystem, particularly within protected areas, must be effectively controlled and managed by the respective authorities in accordance with the legislation that establishes and governs these areas.

To address these challenges and ensure the long-term conservation of biodiversity, it is crucial for TANAPA, TAWA, and other relevant stakeholders to implement comprehensive strategies. These strategies should include robust law enforcement measures to combat illegal hunting, proactive monitoring and management of wildlife populations, targeted initiatives for the recovery of endangered species, and effective management of human activities within protected areas. By adhering to these principles, the ecosystem can be safeguarded, and the ecological balance and integrity preserved for future generations.

4.2. Recommendations

i. It is strongly recommended that the Tanzania Wildlife Management Authority (TAWA) temporarily suspends the allocation of puku hunting quotas until further notice, in light of the rapid decline in the population. Additionally, TAWA should intensify efforts to protect the remaining puku population within the Kilombero Game Reserve. This may involve implementing stricter anti-poaching measures, enhancing habitat conservation, and initiating targeted conservation programs specifically tailored to the needs of the puku species.

ii. Both TAWA and TANAPA should prioritize the control and, where feasible, cessation of human encroachment within their respective jurisdictions across the entire ecosystem. Immediate attention should be given to areas facing significant encroachment pressures, including the recently established Kilombero Game Reserve (under TAWA's jurisdiction), the Selous-Niassa corridor (also under TAWA's jurisdiction), and certain regions within the Nyerere National Park (under TANAPA's jurisdiction). This can be achieved through stricter enforcement of protected area boundaries, community engagement and awareness programs, and the development of sustainable alternative livelihood options for local communities.

iii. The long-term decline observed in several medium to large mammal species, such as buffalo, impala, hippo, elephant, and wildebeest, represents a knowledge gap that necessitates further research. It is crucial to conduct comprehensive scientific investigations to better understand the underlying causes of these population declines. The outcomes of such research will provide valuable insights to conservation managers, enabling them to make informed decisions and develop appropriate conservation strategies to address the challenges faced by these species.

iv. A thorough investigation is warranted regarding the rapid population increase of certain species, such as warthog and duiker, specifically in the eastern part of the ecosystem, particularly in the Liwale and Kilwa districts. This phenomenon requires in-depth research to determine the factors contributing to this population surge. Understanding the drivers behind this increase will help guide management decisions and conservation actions, ensuring that the ecological balance of the ecosystem is maintained and potential implications are properly addressed.

5. ACKNOWLEDGMENTS

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7. APPENDICES

Appendix 1: Flight crew for the 2022 dry season aerial census

Aircraft	**5H-SGR (TAWA)**	**5H-FZS (FZS)**	**5H – SNP (TANAPA)**
Pilot	Hussen Mwangamilla (TANAPA)	Bernard Shayo (FZS)	Ramadhani Bakari(TANAPA)
FSO	Fredrick Mahalafu (TANAPA)	John Sanare (TAWIRI)	Machoke Mwita (TAWIRI)
Left RSO	Greyson Mwakalebe (TAWIRI)	Swahibu Massawe (TANAPA)	Asheeli Loishooki (TANAPA)
Right RSO	Matei Makutiani(TAWA)	Azori Migezo (TAWA)	Albert Mangowi (TANAPA)

Appendix 2: List of ground crew for the 2022 dry season aerial census

Name	**Role**
Dr. Ernest Mjingo	Scientific Supervision
Dr. Edward Kohi and Dr Devolent Mtui	Field Supervision
Dr. Edward Kohi	Logistics and Coordination
Howard Frederick	Survey Technical Advisor
Mr. John Sanare, Mr Maijo Simula, Dr Devolent Mtui	Data entry
Mr. Mwita Machoke, Dr. Edward Kohi and Howard Frederick	Validation and Verification
Mr. Mwita Machoke, Mr. John Sanare and Howard Frederick	Data analysis
Howard Frederick, Mwita Machoke and John Sanare	Mapping & geo-referencing
Dr. Alex Lobora, Dr. Bukombe John, Dr. Hamza Kija, Dr. Edward Kohi, Mwita Machoke, John Sanare, Dr. Devolent Mtui, Goodluck Massawe, Dr Stephen Nindi and Howard Frederick	Reporting

Appendix 3: SRF surveys of wildlife in the Selous Ecosystem, 1976–2022

Year	Season	Survey Area	Area (km^2)	Source
1976	Wet	Selous ecosystem, excluding Kilombero	73,959	Douglas-Hamilton (1976)
1976	Dry	Selous ecosystem, excluding Kilombero	74,131	Douglas-Hamilton (1976)
1981	Wet	North & Eastern Selous GR	19,550	TWCM (1981)
1981	Dry	North & Eastern Selous GR	10,780	TWCM (1981)
1986	Dry	Selous Ecosystem	74,000	Douglas-Hamilton (1986)
1989	Dry	Selous Ecosystem	77,866	Tanzania WD (1989)
1991	Wet	Selous-Mikumi ecosystem	78,551	TWCM (1991)
1994	Dry	Selous-Mikumi ecosystem	91,981	TWCM (1994)
1998	Dry	Selous-Mikumi ecosystem	98,725	TWCM (1999)
2002	Dry	Selous-Mikumi ecosystem	94,009	TAWIRI (2002)
2006	Dry	Selous-Mikumi ecosystem	80,883	TAWIRI (2008)
2009	Dry	Selous-Mikumi ecosystem	80,390	TAWIRI (2009)
2013	Dry	Selous-Mikumi ecosystem	87,421	TAWIRI (2013)
2014	Dry	Selous-Mikumi ecosystem	105,730	TAWIRI (2014)
2018	Dry	Selous-Mikumi ecosystem	104,143	TAWIRI (2018)
2022	Dry	Nyerere-Selous-Mikumi ecosystem	101,537	TAWIRI (2022)

Appendix 4: SRF estimates for all observations types

	Kilombero			Masasi			Mikumi				
	Count	Est	SD	Count	Est	SD	Count	Est	SD	Recce	Total
Wildlife											
Baboon				1	18	19	21	349	238		
Buffalo							206	3,426	3,093	388	3,814
Bushbuck							9	150	93		
Crocodile											
Duiker				30	792	242	4	67	40		
Eland							12	200	149		
Elephant	22	354	260				38	632	312	3	635
Elephant bones - grey											
Elephant bones - white							1	17	16		
Giraffe							24	399	194	2	401
Greater Kudu											
Ground Hornbill				2	37	28	4	67	64		
Hippo	1	12	12	9	174	120					
Hyaena											
Impala							101	1,680	870	43	1,723
Kongoni/Hartebeest				10	245	166	3	50	48		
Puku	33	408	176								
Reedbuck				2	37	40	29	482	338		
Sable Antelope										1	
Warthog	6	107	79				23	383	118		
Waterbuck							1	17	17		
Wild Pig							0	0	0		
Wildebeest				11	202	193	174	2,894	1,274		
Zebra							82	1,364	824		
Livestock											
Cattle	20,937	261,512	15,600	835	23,813	8,655					
Donkey	27	334	133								
Shoats	4,074	50,594	7,836	116	3,367	2,516					
Human activities											
Access Road and Tracks	0	0	0	0	0	0	0	0	0		
Agriculture/Cultivation	0	0	0	4	72	54	0	0	0		
Boma - Abandoned				7	120	58					
Boma - Occupied	259	3,199	407	18	493	302					
Boma - Unoccupied	6	80	36	6	194	183					
Canoe	119	1,470	230	1	35	34					
Charcoal Kiln	1	12	12				2	33	33		
Fallow Land - old	2	25	24	0	0	0					
Fish Camp	29	358	67								
Fish Trap	0	0	0	0	0	0					
Footpath				2	71	51					
Hut, Mabati Roof	535	6,893	954	26	647	193	3	50	49		
Hut, Thatched Roof	1,508	19,098	1,643	795	21,361	3,011	5	83	82	7	90
Mining Camp											
Poachers,- Camp							2	33	22		
Powerline	0	0	0	0	0	0	0	0	0		
Railway Line	0	0	0				0	0	0		
Saw pit	1	12	12	26	640	120	3	50	37	2	52
Tree Felling	0	0	0	3	55	58	0	0	0		
Village	1	18	19	3	106	51					
Waterhole - Dams	2	30	21	9	155	70	0	0	0		

	Out E (Tapika-Ngarambe)			Out Mikumi					Out N (Kidunda-Gonabis)		
	Count	Est	SD	Count	Est	SD	Recce	Total	Count	Est	SD
Wildlife											
Baboon											
Buffalo	102	1,708	1,339						0	0	0
Bushbuck	2	33	22	2	34	31					
Crocodile											
Duiker	11	184	56	1	17	15			6	100	51
Eland									0	0	0
Elephant	18	301	162	1	17	15					
Elephant bones - grey											
Elephant bones - white											
Giraffe											
Greater Kudu	6	100	83								
Ground Hornbill	16	268	105						5	84	79
Hippo				2	34	35					
Hyaena											
Impala	43	720	315						10	167	144
Kongoni/Hartebeest											
Puku											
Reedbuck	1	17	16	1	17	16			1	17	16
Sable Antelope											
Warthog	32	536	170	1	17	17			4	67	66
Waterbuck	6	100	60								
Wild Pig											
Wildebeest	78	1,306	933								
Zebra	16	268	151	51	858	803			5	84	63
Livestock											
Cattle	1,388	23,248	6,886	3,216	54,105	11,335	98	54,203	6,344	105,979	17,761
Donkey				4	67	49			6	100	58
Shoats	387	6,482	3,425	912	15,343	6,073			1,866	31,172	9,421
Human activities											
Access Road and Tracks	1	17	16	0	0	0			0	0	0
Agriculture/Cultivation	0	0	0	6	101	92			0	0	0
Boma - Abandoned	14	234	162	11	185	134	1	186	44	735	257
Boma - Occupied	65	1,089	405	198	3,331	2,666	1	3,332	14	234	91
Boma - Unoccupied	18	301	119	19	320	117			79	1,320	348
Canoe	5	84	67								
Charcoal Kiln				80	1,346	386			1	17	16
Fallow Land - old	0	0	0						0	0	0
Fish Camp											
Fish Trap											
Footpath				2	34	31					
Hut, Mabati Roof	12	201	98	12	202	133			44	735	223
Hut, Thatched Roof	257	4,305	1,175	148	2,490	876			234	3,909	776
Mining Camp											
Poachers,- Camp				5	84	50	1	85			
Powerline	0	0	0	0	0	0			0	0	0
Railway Line									0	0	0
Saw pit	38	636	214	0	0	0			15	251	156
Tree Felling	0	0	0	2	34	19			0	0	0
Village	0	0	0	1	17	17			0	0	0
Waterhole - Dams	0	0	0	2	34	20					

	Out S			Out SE (Liwale)			Out W (Mahenge)				
	Count	Est	SD	Count	Est	SD	Count	Est	SD	Recce	Total
Wildlife											
Baboon	15	263	258	37	663	492				12	12
Buffalo	22	385	369	74	1,327	638	2	33	21	793	826
Bushbuck				6	108	63					
Crocodile											
Duiker	37	648	159	349	6,256	718	4	66	29		
Eland				80	1,434	795	48	797	717		
Elephant	4	70	67	85	1,524	484				55	55
Elephant bones - grey											
Elephant bones - white											
Giraffe											
Greater Kudu				27	484	203					
Ground Hornbill	11	193	76	88	1,578	320				3	3
Hippo				34	609	379					
Hyaena				2	36	35					
Impala	0	0	0	125	2,241	722					
Kongoni/Hartebeest	7	123	118	219	3,926	800	46	764	494		
Puku											
Reedbuck	3	53	28	5	90	57					
Sable Antelope	11	193	112	145	2,599	1,010	7	116	52	6	122
Warthog	2	35	34	294	5,270	1,256	17	282	202	3	285
Waterbuck				2	36	35	35	581	233	3	584
Wild Pig				64	1,147	258					
Wildebeest				5	90	87					
Zebra				85	1,524	567					
Livestock											
Cattle	910	15,931	7,479	10,879	195,020	25,815	677	11,242	4,708	828	12,070
Donkey				10	179	107					
Shoats	89	1,558	1,388	2,687	48,168	8,969	262	4,351	2,087	37	4,388
Human activities											
Access Road and Tracks	0	0	0	444	7,959	4,612	0	0	0		
Agriculture/Cultivation	0	0	0	80	1,434	712	0	0	0		
Boma - Abandoned	1	18	17	97	1,739	417	12	199	98		
Boma - Occupied	17	298	132	559	10,021	3,537	2	33	22	3	36
Boma - Unoccupied	3	53	27	62	1,111	232	28	465	156		
Canoe				1	18	17	4	66	63		
Charcoal Kiln				4	72	55					
Fallow Land - old	0	0	0	77	1,380	885	0	0	0		
Fish Camp											
Fish Trap	0	0	0	2	36	24					
Footpath	0	0	0	0	0	0	0	0	0		
Hut, Mabati Roof	3	53	36	265	4,750	2,308	16	266	108	28	294
Hut, Thatched Roof	132	2,311	1,452	1,318	23,627	3,982	214	3,554	1,141	344	3,898
Mining Camp	3	53	27	0	0	0					
Poachers,- Camp				5	90	46				1	
Powerline				0	0	0	0	0	0		
Railway Line											
Saw pit	2	35	23	723	12,961	4,617	2	33	19	5	38
Tree Felling	0	0	0	817	14,646	5,482	0	0	0		
Village				3	54	30	1	17	15	3	20
Waterhole - Dams	1	18	17	3	54	30	14	232	104		

	Out W (Mbalika)					Selous			elous-Niassa corrid		
	Count	Est	SD	Recce	Total	Count	Est	SD	Count	Est	SD
Wildlife											
Baboon						16	281	209	15	264	178
Buffalo				71	71	848	14,914	3,255	107	1,882	1,495
Bushbuck						11	193	97	6	106	58
Crocodile						5	88	45			
Duiker	0	0	0			142	2,497	234	191	3,360	435
Eland						50	879	392	13	229	118
Elephant	1	17	17	6	23	414	7,281	1,248	45	792	324
Elephant bones - grey						3	53	29			
Elephant bones - white											
Giraffe											
Greater Kudu						25	440	224	2	35	34
Ground Hornbill	1	17	17			95	1,671	285	16	281	103
Hippo						357	6,279	1,590			
Hyaena						4	70	41			
Impala						198	3,482	901			
Kongoni/Hartebeest						316	5,558	884	29	510	269
Puku						3	53	52			
Reedbuck	0	0	0			23	405	161	7	123	55
Sable Antelope						70	1,231	317	92	1,619	596
Warthog						248	4,362	587	39	686	254
Waterbuck						47	827	350	5	88	62
Wild Pig						3	53	38	22	387	177
Wildebeest						561	9,867	2,083			
Zebra						403	7,088	1,021			
Livestock											
Cattle	1,216	20,814	5,893	504	21,318	238	4,186	2,816	3,472	61,082	11,280
Donkey									10	176	170
Shoats	391	6,693	2,365			20	352	339	260	4,574	1,433
Human activities											
Access Road and Tracks	0	0	0			0	0	0	0	0	0
Agriculture/Cultivation	7	120	122			0	0	0	2	35	34
Boma - Abandoned				1	1				28	493	210
Boma - Occupied	31	531	118	4	535	11	193	186	166	2,920	530
Boma - Unoccupied				3					33	581	133
Canoe	1	17	17						2	35	24
Charcoal Kiln	3	51	26						1	18	17
Fallow Land - old	0	0	0			0	0	0	7	123	73
Fish Camp											
Fish Trap									1	18	17
Footpath				1					0	0	0
Hut, Mabati Roof	131	2,242	339	3	2,245	2	35	34	10	176	96
Hut, Thatched Roof	599	10,253	1,583	99	10,352	15	264	181	1,625	28,588	2,979
Mining Camp											
Poachers,- Camp						1	18	17	2	35	24
Powerline	0	0	0						1	18	17
Railway Line											
Saw pit	3	51	28	4	55	5	88	38	19	334	144
Tree Felling	1	17	16			0	0	0	8	141	92
Village	8	137	43						14	246	59
Waterhole - Dams	0	0	0			0	0	0	43	756	212

	Nyerere					Lukwika-Lumusule			Mwambesi NR		
	Count	Est	SD	Recce	Total	Count	Est	SD	Count	Est	SD
Wildlife											
Baboon	57	1,011	426			5	92	58	34	583	541
Buffalo	1,948	34,563	8,116	387	34,950						
Bushbuck	34	603	258								
Crocodile	67	1,189	535								
Duiker	123	2,182	263	1	2,183	7	129	41	25	429	67
Eland	74	1,313	492	50	1,363						
Elephant	467	8,286	929	17	8,303	25	459	495	11	189	106
Elephant bones - grey	3	53	30								
Elephant bones - white	2	35	24								
Giraffe	72	1,277	520								
Greater Kudu	19	337	107						1	17	17
Ground Hornbill	111	1,969	267			2	37	27	1	17	16
Hippo	1,237	21,948	3,808	15	21,963						
Hyaena	2	35	24								
Impala	318	5,642	1,362			3	55	40			
Kongoni/Hartebeest	405	7,186	1,286								
Puku	2	35	34								
Reedbuck	54	958	379								
Sable Antelope	159	2,821	576	10	2,831				24	412	279
Warthog	113	2,005	301			2	37	38	1	17	16
Waterbuck	253	4,489	786	2	4,491						
Wild Pig	11	195	95								
Wildebeest	265	4,702	1,251								
Zebra	309	5,483	792	2	5,485						
Livestock											
Cattle	861	15,277	4,718	70	15,347						
Donkey											
Shoats	205	3,637	1,467	75	3,712						
Human activities											
Access Road and Tracks	6	106	87						0	0	0
Agriculture/Cultivation	13	231	225			0	0	0	0	0	0
Boma - Abandoned	2	35	24						1	17	17
Boma - Occupied	38	674	195	1	675						
Boma - Unoccupied	1	18	17								
Canoe	5	89	86						2	34	36
Charcoal Kiln	1	18	17								
Fallow Land - old	0	0	0	21		0	0	0	0	0	0
Fish Camp	2	35	34								
Fish Trap											
Footpath	0	0	0								
Hut, Mabati Roof	10	177	77								
Hut, Thatched Roof	198	3,513	887	40	3,553	2	37	20	8	137	102
Mining Camp											
Poachers,- Camp	2	35	24								
Powerline	0	0	0								
Railway Line	0	0	0								
Saw pit	26	461	189	1	462	1	18	13	5	86	66
Tree Felling	100	1,774	1,571								
Village	0	0	0								
Waterhole - Dams	3	53	38								

	OUT					Total				
	Count	Est	SD	Recce	Total	Total Count	Total Est	Total SD	Recce	Total
Wildlife										
Baboon						201	3,525	958	12	3,537
Buffalo						3,309	58,239	9,518	1,639	59,878
Bushbuck						70	1,227	305		
Crocodile						72	1,277	536		
Duiker	1	17	17			931	16,745	963	13	16,758
Eland						277	4,852	1,256	50	4,902
Elephant						1,131	19,921	1,793	85	20,006
Elephant bones - grey						6	106	42		
Elephant bones - white						3	52	29		
Giraffe						96	1,677	555	2	1,679
Greater Kudu						80	1,414	333		
Ground Hornbill						352	6,218	543	7	6,225
Hippo						1,640	29,056	4,146	15	29,071
Hyaena						8	142	59		
Impala						798	13,988	2,016	43	14,031
Kongoni/Hartebeest						1,035	18,361	1,853		
Puku						38	496	186		
Reedbuck						126	2,197	541		
Sable Antelope						508	8,991	1,379	17	9,008
Warthog						782	13,803	1,475	3	13,806
Waterbuck						349	6,138	897	18	6,156
Wild Pig						100	1,782	330		
Wildebeest						1,094	19,060	2,906		
Zebra						951	16,667	1,828	2	16,669
Livestock										
Cattle	429	7,203	4,175			51,402	799,411	41,997	2,678	802,089
Donkey						57	856	252	11	867
Shoats	181	3,039	1,642			11,450	179,330	17,448	143	179,473
Human activities										
Access Road and Tracks	0	0	0			451	8,082	4,613		
Agriculture/Cultivation	0	0	0			112	1,993	765		
Boma - Abandoned	1	17	17			218	3,793	585	6	3,799
Boma - Occupied	1	17	17	2	19	1,379	23,034	4,520	21	23,055
Boma - Unoccupied	2	34	33			257	4,476	531	10	4,486
Canoe						140	1,849	269	1	1,850
Charcoal Kiln	1	17	17			94	1,583	394		
Fallow Land - old						86	1,528	888	24	1,552
Fish Camp						31	394	75		
Fish Trap						3	53	30	1	54
Footpath						4	105	60	1	106
Hut, Mabati Roof	23	386	209	2	388	1,092	16,813	2,558	47	16,860
Hut, Thatched Roof	27	453	169			7,085	123,982	6,784	575	124,557
Mining Camp						3	53	27		
Poachers,- Camp	1	17	17			18	312	83	2	314
Powerline	0	0	0			1	18	17	1	19
Railway Line	0	0	0			0	0	0		
Saw pit						869	15,657	4,633	13	15,670
Tree Felling	1	17	17			932	16,683	5,703		
Village	0	0	0			31	595	98	3	598
Waterhole - Dams						77	1,332	253		

Tanzania Wildlife Research Institute (TAWIRI)
P.O.Box 661
Arusha - Tanzania

T: +255 27 254 9471
F: +255 27 254 8240
Email: barua@tawiri.or.tz
Website: www.tawiri.or.tz