STATUS AND DISTRIBUTION OF WILDLIFE, LIVESTOCK AND BOMAS IN AND AROUND SERENGETI ECOSYSTEM, TANZANIA

Conducted by

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COOPERATION AND COLLABORATION

The successful implementation of the Serengeti Ecosystem Aerial Survey was a product of thorough planning, hard work, and good collaboration between government and non-governmental partners. The following partner institutions collaborated with TAWIRI for the successful implementation:

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Wildlife Division works to conserve, manage and develop wildlife and wetlands resources, and fosters sustainable utilization that will contribute towards poverty reduction.

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

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Ngorongoro Conservation Area Authority (NCAA) cooperates with NCA indigenous residents to conserve the natural and historical resources of this World Heritage Site while providing optimal social services to residents, staff and visitors.

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

EXECUTIVE SUMMARY

An aerial Census of wildlife, livestock and bomas was conducted in the Serengeti ecosystem from 22nd August to 10th September 2016 in order to assess the level of human wildlife interaction. The Serengeti Ecosystem comprises of Serengeti National Park, Ngorongoro Conservation Area (NCA), Maswa, Ikorongo, Grumeti, and Kijereshi Game Reserves (GR); and Loliondo Game Controlled Area (GCA), IKONA and Makao Wildlife Management Area (WMAs). The survey aimed to provide a comprehensive baseline dataset on wildlife distribution and external wildlife pressure, mainly livestock, cultivation and settlements. Data were collected using Aerial point survey (APS) method, where photographs were taken along transects flown in various orientations with 2km spacing. The surveyed area covered 20 km distance outside the protected area boundary in certain districts and 10 km inside Serengeti National Park. The 20km distance from the protected area boundary covered parts of Tarime, Serengeti, Itirima, Meatu, Bariadi, Busega, Bunda and Butiama districts. Protected Areas that were covered entirely are; NCA, Maswa, Ikorongo, Kijereshi and Grumeti Game Reserves; and Loliondo Game Controlled Area, IKONA and Makao WMAs.

This report presents results on the distribution and/or estimate of wildlife, livestock, boma and settlements. A total of eleven wildlife species were recorded in the surveyed area, these include zebra, wildebeest, topi, kongoni, elephant, buffalo, impala, giraffe, eland, hippo and ostrich. Serengeti National Park had an estimate of 40,251 ±19,679 (3.3% of the total livestock), Ngorongoro Conservation Area with an estimate of 115,562 ±16,053 (9.5%), Maswa GR with an estimate of 22,258 ±8,525 (1.8%), Ikorongo GR with an estimate of 3,710 ±2,006 (0.3%), Grumeti GR with an estimate of 533 ±431 (0.04%); and Loliondo GCA with an estimate of 167,667 ±31,985 (13.9%). The population of shoats was estimated to be 981,723 ±59,726 whereby Serengeti National Park has an estimate of 33,034 ±16,053 (3.1% of the total shoats), Ngorongoro Conservation Area with an estimate of 181,281 ±23,947 (19%), Maswa GR with an estimate of 5,225 ±1,985 (0.5%), Ikorongo GR with an estimate of 2,178 ±1,176 (0.1%), Grumeti GR with an estimate of 1,523 ±800 (0.15%); and Loliondo GCA with an estimate of 238,123 ±45,195 (24.5%).

Estimated number of settlements inside protected areas was 8,680 ±452, bomas with an estimate of 12,072 ±562, donkey with an estimate of 764 ±348. There were only 5 camel observed in the entire surveyed area.

RECOMMENDATIONS

- Census results shows that wildlife are found outside protected area boundaries into villages lands that could results in human wildlife conflict. It is recommended this data could be used by Management authorities' to mitigate wildlife human conflict.
- Livestock were observed in protected areas where grazing is not allowed. There is a need to enhance law enforcement in Serengeti National Park, Maswa, Ikorongo, Kijereshi and Grumeti GR to prevent livestock from using these protected areas.
- APS data are rich in information that provide opportunity for further analyses for additional variable such as ecological or social economic information from photos
- Further studies are recommended to validate the accuracy of using APS in estimating the abundance of livestock and wildlife.

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LIST OF ABREVIATION AND ACRONYMS

APS	Aerial Point Survey
CA	Conservation Area
CIMU	Conservation Information and Monitoring Unit
FSO	Front Seat Observer
FZS	Frankfurt Zoological Society
GCA	Game Controlled Area
GPS	Global Positioning System
GR	Game Reserve
GGR	Grumeti Game Reserve
IGR	Ikorongo Game Reserve
IKONA	Ikoma and Nata Wildlife Management Area
LGCA	Loliondo Game Controlled Area
NCA	Ngorongoro Conservation Area
NCAA	Ngorongoro Conservation Area Authority
SNP	Serengeti National Park
NP	National Park
PA	Protected Area
SENAPA	Serengeti National Park
SHOATS	Sheep and goat
SRF	Systematic Reconnaissance Flight
TANAPA	Tanzania National Parks
TAWIRI	Tanzania Wildlife Research Institute
TC	Total Count
TWCM	Tanzania Wildlife Conservation Monitoring
WD	Wildlife Division
WMA	Wildlife Management Area

1. INTRODUCTION

1.1 Background Information

The Serengeti ecosystem is one of the seven key ecosystems for wildlife conservation in Tanzania, The ecosystem is approximately 33,185 km² (Sinclair and Arcese, 1995) and comprises nine administrative areas. The areas include Serengeti National Park (SENAPA), Ngorongoro Conservation Area (NCA), Maswa, Ikorongo, Kijereshi and Grumeti Game Reserves, Loliondo Game Controlled Area and IKONA and Makao Wildlife Management areas (WMAs) (Figure 1). Aerial wildlife censuses have been carried out in the ecosystem since 1957 using various methods including Systematic Reconnaissance Flight (SRF), Total Counts (TC) and Aerial Point Survey (APS).

1.2 Survey Objectives

The objectives of this Aerial Point Survey (APS) in the Serengeti Ecosystem were: (i) to determine numbers and density of wildlife and livestock; (ii) to show presence and absence of bomas and human settlements and, (iii) to map the spatial distribution of wildlife, livestock and human settlements.

1.3 Survey Rationale

Wildlife conservation as a land use is competing with other land uses such as farming, pastoralism and settlement. Pastoralism practices may have increasing impact on wildlife areas, due to increasing pressure on limited grazing land, which drives an increase in illegal grazing and conflicts between pastoralists and the protected areas authorities. Increasing livestock also affects the livelihoods of pastoral communities as the herds exceed carrying capacity of the land and the livestock become more susceptible to climate shifts and drought. Additional pressure is placed on villages without formal land-use plans when livestock is brought into the ecosystem in search of grazing land. For sustainable wildlife conservation it is important to understand the direct pressure/threat from increasingly competition with wildlife in grazing and well as water resources. Understanding spatial distribution of livestock and bomas in and around the Serengeti ecosystem can help inform sustainable land-use practices, and will be instrumental in facilitating land-use planning, as well as evaluating the impact of these interventions. However, very limited data and information is available regarding wildlife and livestock numbers at the greater ecosystem level especially outside of protected areas and accuracy of existing non-aerial census methods is highly variable, often relying solely on reporting by owners themselves (e.g., the Tanzanian National Census, 2012). Wildlife and livestock often compete for grazing areas, while pressure on protected

areas is increasing and often leads to boundary conflicts and degraded relationship between the protected area authorities and the local communities. There is an urgent need for the Protected Area managers, village leaders and District Councils to better understand the current status of wildlife and livestock adjacent to protected areas to provide a basis on finding sustainable solutions for both conservation and the local communities.

Table 1: Recent surveys in the Serengeti ecosystem (1989-2016)

Year	***Season***	***Area covered***	***Method***	***Area (km²)***	***Source***
1989	Dry	Serengeti Ecosystem	SRF	27,541	TWCM (1989)
1991	Wet	Serengeti Ecosystem	SRF	26,084	TWCM (1991)
1996	Dry	Serengeti Ecosystem	SRF	27,992	TWCM (1996)
2001	Wet	Serengeti Ecosystem	SRF	26,870	TWCM (2007)
2003	Wet	Serengeti Ecosystem	SRF	31,157	TAWIRI (2003)
2006	Wet	Serengeti Ecosystem	SRF	27,113	TAWIRI (2008)
2010	Wet	Serengeti Ecosystem	SRF	26,827	TAWIRI (2008)
2014	Wet	Serengeti Ecosystem	TC	32,000	TAWIRI (2014)
2016	Dry	Serengeti Ecosystem	APS	32,558	This report

Photo 1: Sample photo of livestock and bomas in the Serengeti ecosystem.

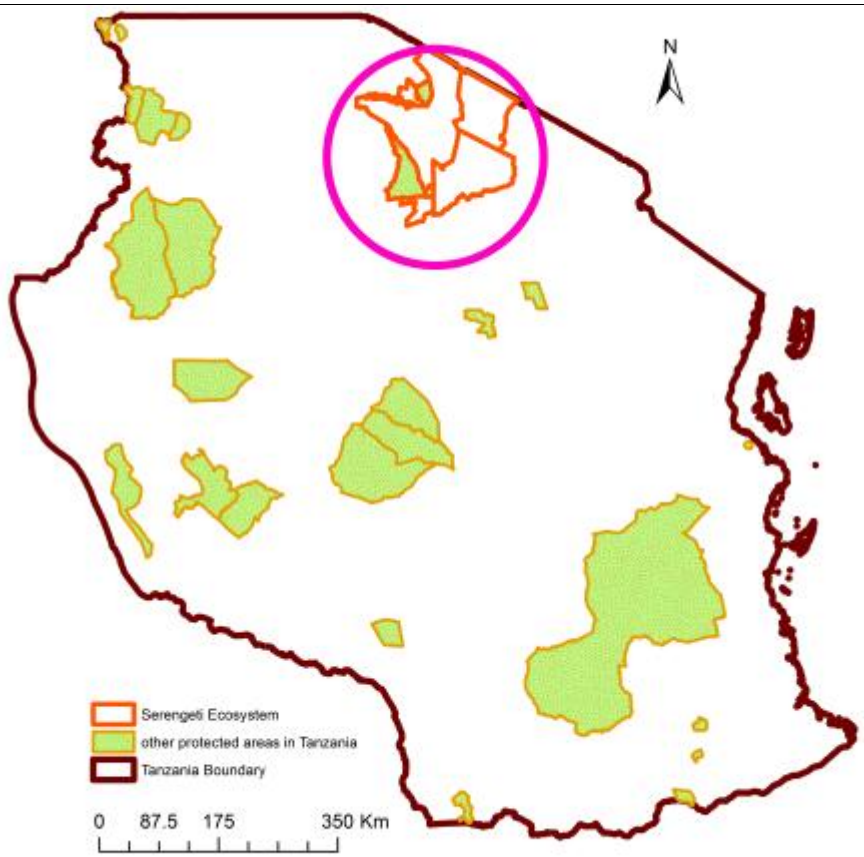

Figure 1: Location of the Serengeti ecosystem (circled) in Tanzania and its position relative to other protected areas.

2. SURVEY AREA

2.1 Location

The Serengeti ecosystem covers an area of 33,185 km² in Northern Tanzania between 34° and 36° Longitude and 1° 30’ to 3° 30’ Latitude.

2.2 Administrative Areas

The survey covered the following protected areas in their entirety NCA, Maswa, Ikorongo, and Grumeti Game Reserves and Loliondo Game Controlled Area. The survey also partially covered the IKONA Wildlife Management Area (WMA, 723 km^2) and Makao Wildlife Management Area (WMA 1,145 km^2). The remaining areas consisted of a buffer of 20 km extending outside the protected area boundary and 10 km inside Serengeti National Park. The survey included parts of the following political administration districts Tarime, Serengeti, Itirima, Meatu, Ngorongoro, Bariadi, Busega , Karatu, Butiama and Bunda.

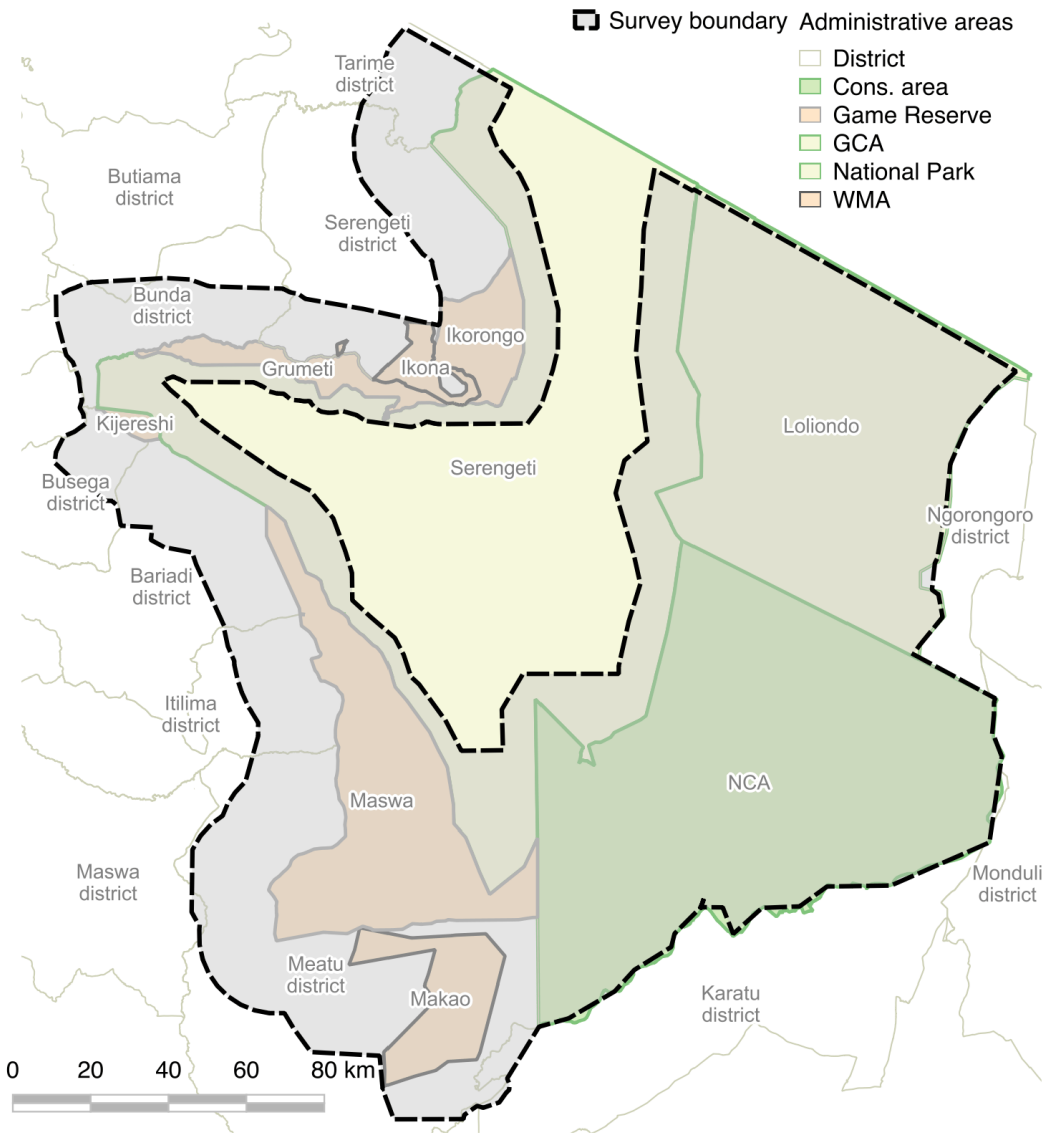

Figure 2: *The Serengeti ecosystem showing Serengeti Ecosystem and districts covered (survey area is shaded grey)*

2.3 Climate and Hydrology

The climate of the Serengeti ecosystem is tropical. It is usually warm and dry, with mean monthly maximum temperature of 27-28°C all year round and a mean monthly minimum temperature of 13-16°C (Sinclair and Arcese 1995; Sinclair *et al*., 2000). There are distinct wet and dry seasons, with rainfall determined by topographic relief, and the seasonal movement of world air masses, which form the inter-tropical convergence zone (ITCZ). This belt of rain-laden winds moves north and south across the equator and brings two main periods of rain from March to June and November to December. The rainfall pattern is often erratic, with both extreme wet and dry years, and variations occurring depending on location: there is a north to south and west to east rainfall gradient, with

the northern and western parts receiving more rainfall than the southern and eastern parts. The middle ranges receive 900-1000mm/year while lowlands like the eastern Serengeti Plains are the most arid with 500-800mm/year.

The Mara River is the main perennial source of available surface water both for wildlife and human use. Other important rivers in the ecosystem include the seasonal Sand, Orangi-Grumeti and Mbalageti rivers. Studies have established two peaks in the Mara River water discharge that correspond to the peaks in the rainfall pattern. Although the Mara River is typically permanently flowing, drought and erratic rainfall coupled with unprecedented destruction of the water catchment area pose a threat to this important water source.

2.4 Topography and Soils

The topography and soils of the Serengeti ecosystem are comprehensively covered in the Serengeti-Masai Mara trans-boundary protection and monitoring plan (EAC, 2012). The basement complex of the ecosystem is made of pre-Cambrian igneous and metamorphic rocks. Erosion and volcanic activities have changed the surface of this ecosystem to the present topographic forms characterized by extensive plains, hill crops, escarpments and valleys. The rangelands and escarpments are characterized by rich volcanic soils while poorly drained brown soils occur in the plateaus and plains where extensive grasslands are common. River basins and valleys have clay soils enriched with accumulated sediments (EAC, 2012).

2.5 Fauna

The Serengeti plains are internationally recognized for having the highest density and most diverse combination of large herbivores on earth, some of which are renowned for their seasonal migration between the Serengeti and Masai-Mara plains. The major herbivores include the African elephant (*Loxodonta africana*), Cape buffalo (*Syncerus caffer*), wildebeest *(Connochaetes taurinus),* Cape eland (*Taurotragus oryx*), Coke's hartebeest (*Alcephalus buselaphus cokii*), Burchell's zebra (*Equus quagga burchelli*), impala (*Aepyceros melampus*), giraffe (*Giraffa camelopardalis)*, black rhinoceros (*Diceros bicornis*), hippopotamus (*Hippopotamus amphibius*) and Grant's gazelle (*Gazella grantii*).

The common carnivores are leopard (*Panthera pardus*), lion (*Panthera leo*), cheetah (*Acinonyx jubatus*) black-backed jackal (*Canis mesomelas*), African wild dog (*Lycaon pictus*), spotted hyaena

(*Crocuta crocuta*). Other species found in the ecosystem include the olive baboon (*Papio anubis*), vervet monkey (*Chlorocebus pygerythrus*), black and white colobus (*Colobus satanas)* and Patas monkeys (*Erythrocebus patas*).

2.6 Flora

Savanna grasslands and acacia woodlands form the major vegetation types of the Serengeti ecosystem. The dominant tree species includes *Acacia seyal* var. *fistula*, *Acacia tortilis*, *Acacia polyacantha* and *Euphorbia candelabrum* while the dominant grass species are *Eragrostis cyndiflora, Chloris pycnothrix, Pennisetum meziannum* and *Themeda triandra (Rusch et al. 2005)*.

2.7 Economic Activities

The Serengeti ecosystem supports a number of economic activities, the most important of which is photographic tourism, providing a significant part of Tanzania's Gross Domestic Product. The two main protected areas; Serengeti National Park and Ngorongoro Conservation Area, are the most visited protected areas in the country. Livestock rearing is common practice in surrounding communities keeping primarily cattle, sheep and goats. Sports hunting only is practiced in the game reserves game controlled areas and WMAs only. Charcoal production, agricultural activities, mining, logging and other forms of land use also take place in the unprotected parts of the ecosystem. With increasing human population (Tanzania's population is growing at around 3.5% per annum), the socio-economic arrangement of the ecosystem is rapidly changing, and competition among different land users (pastoralists, farmers, tourism industries and conservationist) are evident. The various forms of land use help to provide livelihoods to local communities but, if not carefully managed conflicting incentives amongst different actors may result in habitat degradation.

3. MATERIALS AND METHODS

3.1 Survey design and flight plan

An Aerial Point Survey (APS) sample method was employed for the 2016 dry season wildlife, livestock and boma survey, from 22 August to10th September 2016. The survey area was initially defined as a buffer of 10km inside and 20km outside of Serengeti National Park, plus the entirety of Ngorongoro Conservation Area, Loliondo Game Controlled Area, and the whole of Maswa Game Reserve plus a buffer of 20km outside of Maswa GR.

A total of 419 parallel transects with 2km spacing interval were planned with a total distance of 16,290km and expected coverage of about 32,000 km².

The distance of 20km from the protected area boundary included parts of the following districts, Tarime, Serengeti, Itirima, Meatu, Bariadi, Busega , Karatu, Bunda and Butiama (Table 2). NCA, Maswa, Ikorongo, Kijereshi and Grumeti Game Reserves; and Loliondo Game Controlled Area, IKONA and Makao Wildlife Management Areas were covered entirely.

Table 2: Percentage covered in relation to total district area

District name	Area_covered (km^2)	District_total area (km^2)	Percentage (%)
Bariadi	2,553	5,484	46.56
Busega	1,212	1311	92.45
Bunda	145	3,092	4.69
Serengeti	3,207	10,373	30.92
Meatu	2,937	9,017	32.57
Itilima	2,581	4,690	55.03
Ngorongoro	14,217	15,639	90.91
Tarime	150	1,534	9.78
Total	**27,002**	**51,140**	

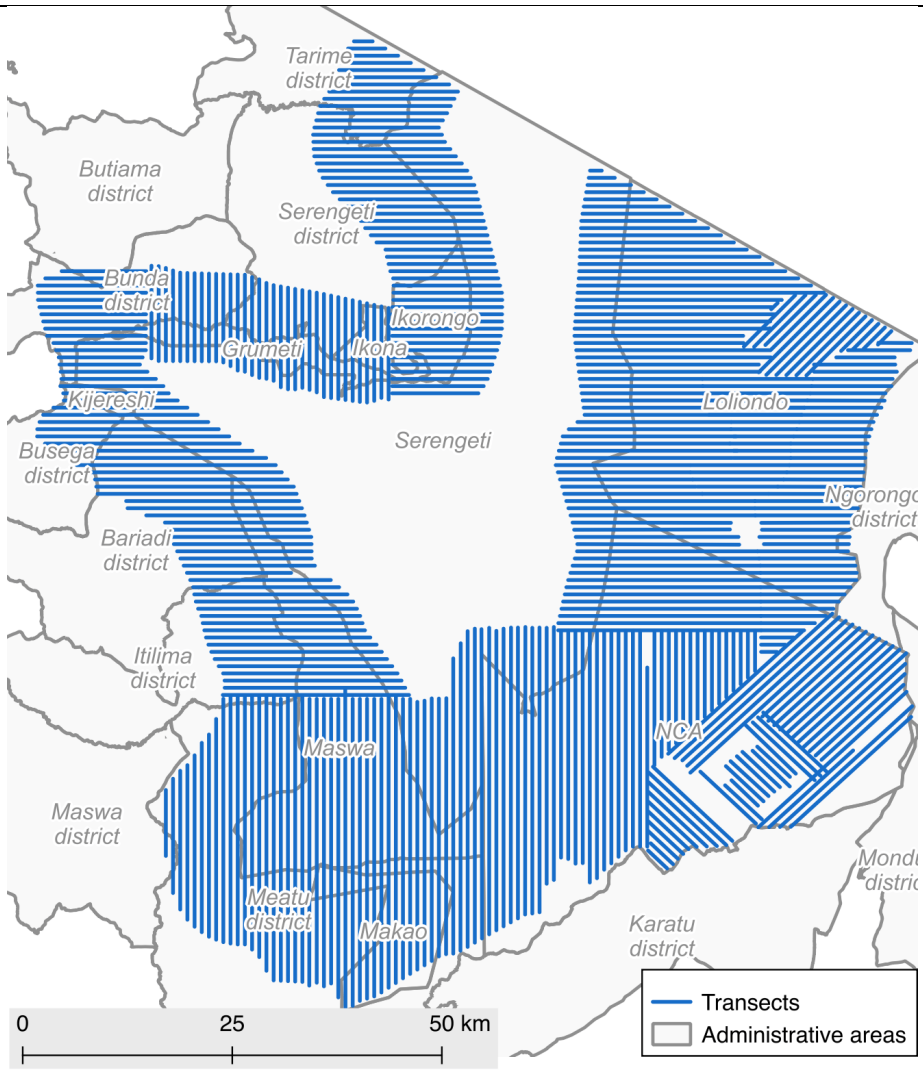

Figure 2: Planned transects of Serengeti ecosystem APS

Training of Survey Crew

Survey crews for each flight were composed of a pilot and a camera operator:

- Pilot: responsible for navigation, maintaining a constant height above ground (about 455m) above ground level (AGL), and flying straight and level during transects. All pilots were experienced survey pilots from normal transect surveys (SRF) and needed minimal training.
- Camera operator: responsible for monitoring and triggering camera operation at the beginning of transects, assisting with navigation and equipment checks pre-flight.

Two hours training flights were made before work began, to ensure correct operation of equipment, test resolution of acquired photos, and confirm straight and level flight.

Data Capture

The aerial survey was conducted following the for APS method as described by Norton-Griffiths (1973).

- Nikon D3200 cameras with Nikkor 28mm lenses were affixed to the struts of Cessna 182 and 206 aircrafts. Camera orientation was set for 90° vertical images at flight altitude (using top of door frame for flight level reference).
- Photographs were triggered at approximately 3 seconds intervals using Digicam and GPhoto2 software and USB cables, targeting the capture of 4 images per kilometre flown. All images were stored on the SD cards of the cameras.
- Images captured were JPG (fine) with target resolution of 5 cm; average resolution of all images was 5.5 cm after analysis.
- Image resolution was determined from GSD calculations using the height AGL calculated from GPS elevation and the SRTM3 Digital Elevation Model (DEM).

A Global Positioning System (GPS) was used for navigation and recording locations; heights were maintained along transects by regular reference to target heights MSL calculated from the DEM. In addition, Garmin GPSmap 64s were used to record track log of flight path of each aircraft. The nominal altitude was maintained at ~455 m above the ground. Each photo area on the ground was approximately 60,000 square meters.

A total of 99,903 photographs were taken, of which 90,950 were retained for analysis after excluding photos that were taken at turns and areas outside of planned transects. Figure 4 shows the overall coverage (blue = selected photos, red = excluded), together with a detail flown tracklog showing the included and excluded photos on individual flight lines. Photographs were then counted and some recounted.

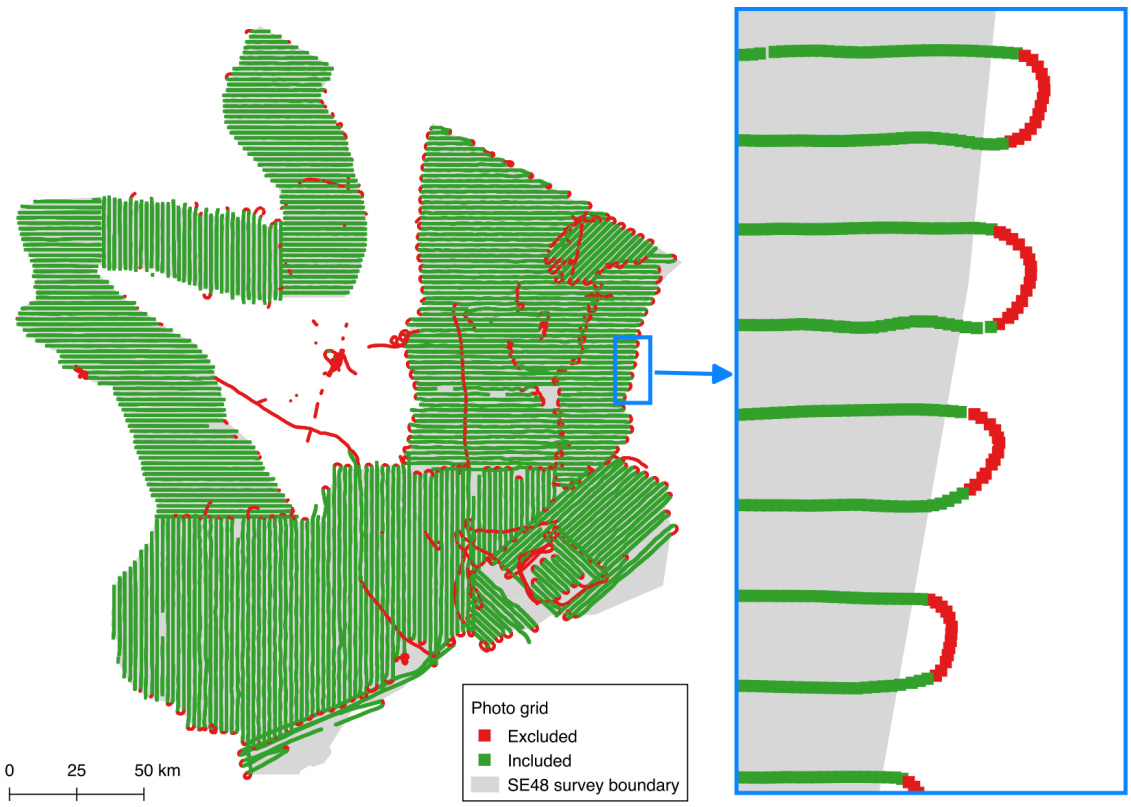

Figure 3: Indicating included (green) and excluded (red) photos in the analysis.

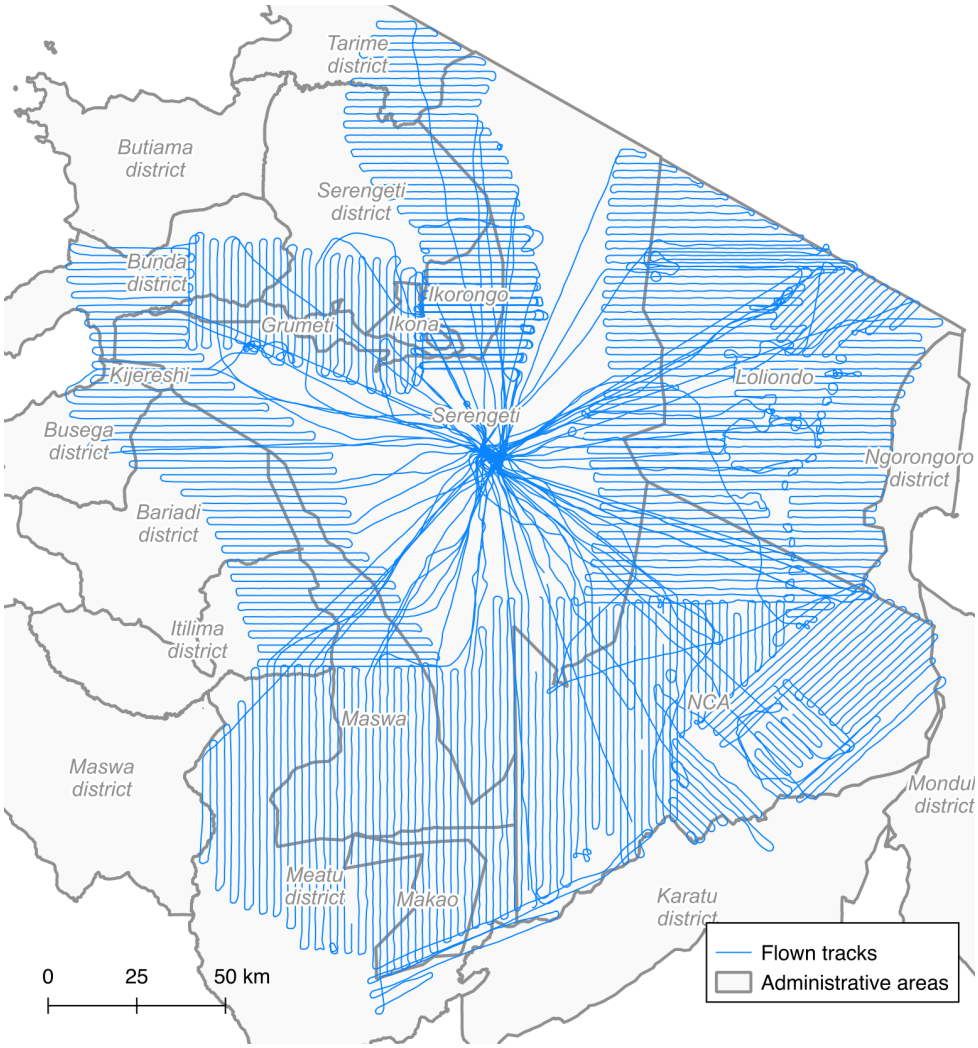

Figure 4: Track-logs of flown flight lines and transit flights to transect to and from the Seronera Airstrip, Serengeti National Park

3.2 Lab work

Photographs were selected systematically from the dataset and counted and re-counted by a set of 26 enumerators in Serengeti and later in the TAWIRI Office.

- Counters were given a spreadsheet with clickable links to individual photographs, and fillable data fields.
- Each photo was opened in an image viewer, zoomed to 50%, moved to the upper left part of the image, and then systematically 'clicked through' using the scroll bars on top and side of the screen. Counters were allowed to use contrast enhancement as needed.
- Large herds of animals were counted using ImageJ's point count tool.
- Data were entered back into the spreadsheet.

A counting protocol was established:

- **Initial count**: a minimum of 1 photograph per 1 km of flight lines is selected for counting (~ 15,000 images);
- Each photograph was scanned for the presence of Livestock, Wildlife, Settlements, Water and other features;
- Each group of animals was identified (livestock / cattle, wildlife species) and counted (individual animals are clicked on and counted using ImageJ Software),
- **Secondary counts**: a set of the 'positive' photographs with an animal herd was returned to the same set of counters for re-count, to check the variation in identification and group size 10% of the 'negatives' (no detections of animals) was returned at random to the counters, to examine the false-negative rate.

1.1 Data analysis

The estimated number of livestock per transect was obtained by multiplying the number of animals counted per transect by the proportion of photographed area per transect (Norton-Griffiths 1973). Jolly's Method 2 of Unequal Sized Units (Jolly 1969) was used to calculate population estimate and 95% confidence limits (see section **8.3**). Records of presence and absence of boma on each photo were recorded; this information was used to create a map showing spatial distribution of bomas in the surveyed area.

1.2 Minimising biases

A comprehensive list of potential errors may be found in the aforementioned references, and in this particular survey the following possible sources of bias were identified:

- Incomplete coverage of the planned survey area in some parts of the census zone due to difficult topography. Some parts of Lake Eyasi, Ngorongoro highland and Satiman mountain, were not counted due to difficult terrain, strong winds and clouds. The estimates are based on average density of animals – if the average density of a species would have been lower in the mountains it should reduce the overall estimate; thus missing out the mountainous area could represent a bias.

- However, it is expected that the effect of this bias was very small since the area is only around 1% of the total area (351 km² out of > 30,000 km²).

- Visibility bias: missing animals hidden under tree canopy especially in gallery forests in the Ngorongoro highlands;
    - The magnitude of this bias is difficult to estimate, and may represent a substantial undercount of forested areas (< 10% of the survey area).

- An aircraft tilt altered photo coverage on targeted ground area. Bank angles greater than 3° can lead to increases in photo geometry of 5% - this would lead to an overestimate of numbers.
    - Photos with high bank angle (and thus oblique photographic angle) were removed. These were rarely mid-transect, generally only at the end of transects (turns).

- High flying height changed the desired resolution, therefore caused difficult in counting activities.
    - Photos with very low resolution per pixel (> 15cm) were removed

4. RESULTS

4.1 Wildlife population distribution

A total of eleven wildlife species were recorded in the surveyed area, these include zebra, wildebeest, topi, kongoni, elephant, buffalo, impala, giraffe, eland, hippo and ostrich. The distribution pattern of wildlife in the surveyed area shows that relatively high concentration of wildlife was recorded in the western part while scattered distribution in the eastern part. The result shows that wildlife shared space with livestock over the surveyed area (figure 5), which is more pronounced in the eastern part of the ecosystem. The highest territory sharing was observed in the Ngorongoro Conservation Area followed by Loliondo Game Controlled Area. Where there is high concentration of livestock and other human activities wildlife is apparently absent. In the north-west and south west of the surveyed area wildlife seems to be pushed back from the national park and game reserve boundaries along the areas of highest concentration of livestock.

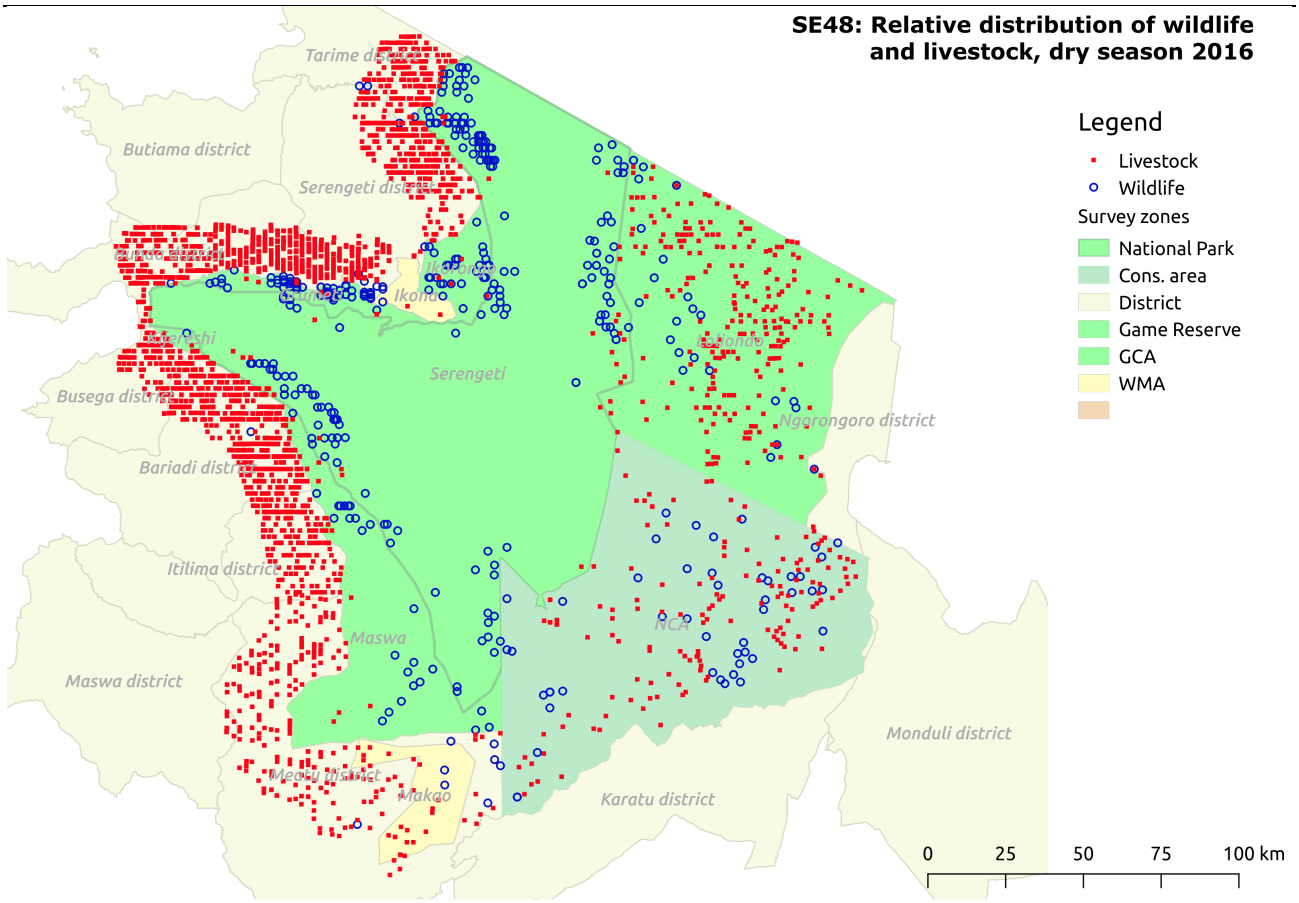

Figure 5: Relative distribution of wildlife and livestock in the Serengeti ecosystem, dry season 2016

4.2 Livestock, bomas and settlement

In the dry season 2016 aerial survey in the Serengeti ecosystem cattle, shoats, settlement, donkeys and camels estimates were generated over the entire census zone (Table 2), and for all protected area (Table 3). Similarly, the same estimates were generated for each administrative area (Table 4).

Table 3: Livestock, boma and settlement estimates in the surveyed area

Livestock and settlement	Observed	Estimates	SE
Cattle	108,646	1,210,847	54,098
Shoats	92,261	981,723	156,229
Donkey	145	1,593	412
Camel	5	*72*	*25*
Settlement	4,773	54,983	1,275
Boma	4,555	53,044	1,238

Table 4: Livestock, boma and settlement estimate in all protected areas

Livestock and settlement	Observed	Estimate	SE
Cattle	35,020	368,191	42,047
Shoats	48,521	480,007	53,846
Donkey	82	764	348
Camel	0	0	0
Settlement	845	8,680	452
Boma	1,194	12,072	562

Table 5: Survey estimates per administrative area

	Boma			Cattle			Donkey			Settlement			Shoats		
	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.
Grumeti GR	1	8	7	70	533	431	0	0	0	3	23	12	200	1,523	800
Ikona WMA	3	43	48	60	863	969	0	0	0	11	158	80	118	1,697	2,218
Ikorongo GR	5	134	64	138	3,710	2,006	0	0	0	3	81	36	81	2,178	1,177
Kijereshi GR	1	18	16	141	2,506	1,295	0	0	0	2	36	22	79	1,404	631
Loliondo GCA	643	5,806	395	18569	167,667	31,985	72	650	309	466	4,208	322	26372	238,123	45,195
Makao WMA	51	917	164	825	14,841	4,517	1	18	10	34	612	127	864	15,542	3,792
Maswa GR	17	344	101	1099	22,258	8,525	0	0	0	23	466	144	258	5,225	1,985
NCA	447	4,311	318	11982	115,562	16,053	8	77	158	284	2,739	215	18796	181,281	23,947
Serengeti NP	26	490	120	2136	40,251	19,679	1	19	24	19	358	94	1753	33,034	16,053

Table 6: Survey Estimates per District

	Boma			Camel			Cattle			Donkey			Settlement			Shoats		
District Name	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.	Count	Est	S.E.
Bariadi district	671	6,388	343	0	0	0	16,020	152,502	14,730	10	95	43	749	7,130	330	6,586	62,695	9,043
Bunda district	564	3,814	239	0	0	0	16,290	110,146	8,371	1	7	6	877	5,930	295	11,930	80,666	6,855
Busega district	152	1,857	127	0	0	0	2,960	36,157	3,712	7	86	63	176	2,150	147	1,376	16,808	2,418
Butiama district	22	139	26	0	0	0	921	5,804	1,539	0	0	0	23	145	29	200	1,260	406
Itilima district	408	5,053	187	1	12	9	5,027	62,258	4,906	12	149	78	482	5,969	155	2,697	33,401	5,510
Maswa district	7	140	48	0	0	0	171	3,410	2,364	0	0	0	7	140	48	111	2,213	807
Meatu district	672	11,983	681	2	36	22	12,814	228,488	20,985	17	303	114	790	14,087	858	8,706	155,238	16,583
Ngorongoro district	1,090	10,117	507	0	0	0	30,551	283,299	35,788	80	727	347	750	6,947	387	45,168	419,404	51,147
Serengeti district	651	7,700	661	2	24	8	17,235	203,851	18,605	16	189	154	666	7,877	542	11,220	132,707	14,414
Tarime district	213	3,898	294	0	0	0	2,188	40,040	6,265	0	0	0	157	2,873	383	914	16,726	4,396

4.2.1 Cattle

Cattle were the most abundant and numerous livestock among human activities in the surveyed. A total of 1,210,846 ±54,098 cattle were estimated in the entire surveyed area (Table 2). Serengeti National Park had an estimate of 40,251 ±19,679 about 3.3% of the total, Ngorongoro Conservation Area with an estimate of 115,562 ±16,053 about 9.5%, Maswa GR with an estimate of 22,258 ±8,525 about 1.8%, Ikorongo GR with an estimate of 3,710 ±2,006 about 0.3%, Grumeti GR with an estimate of 533 ±431 about 0.04%; and Loliondo GCA with an estimate of 167,667 ±31,985 about 13.9%. Cattle were distributed all over outside the protected area with the highest density record along the North West and Southern parts of the surveyed area (Figure 6).

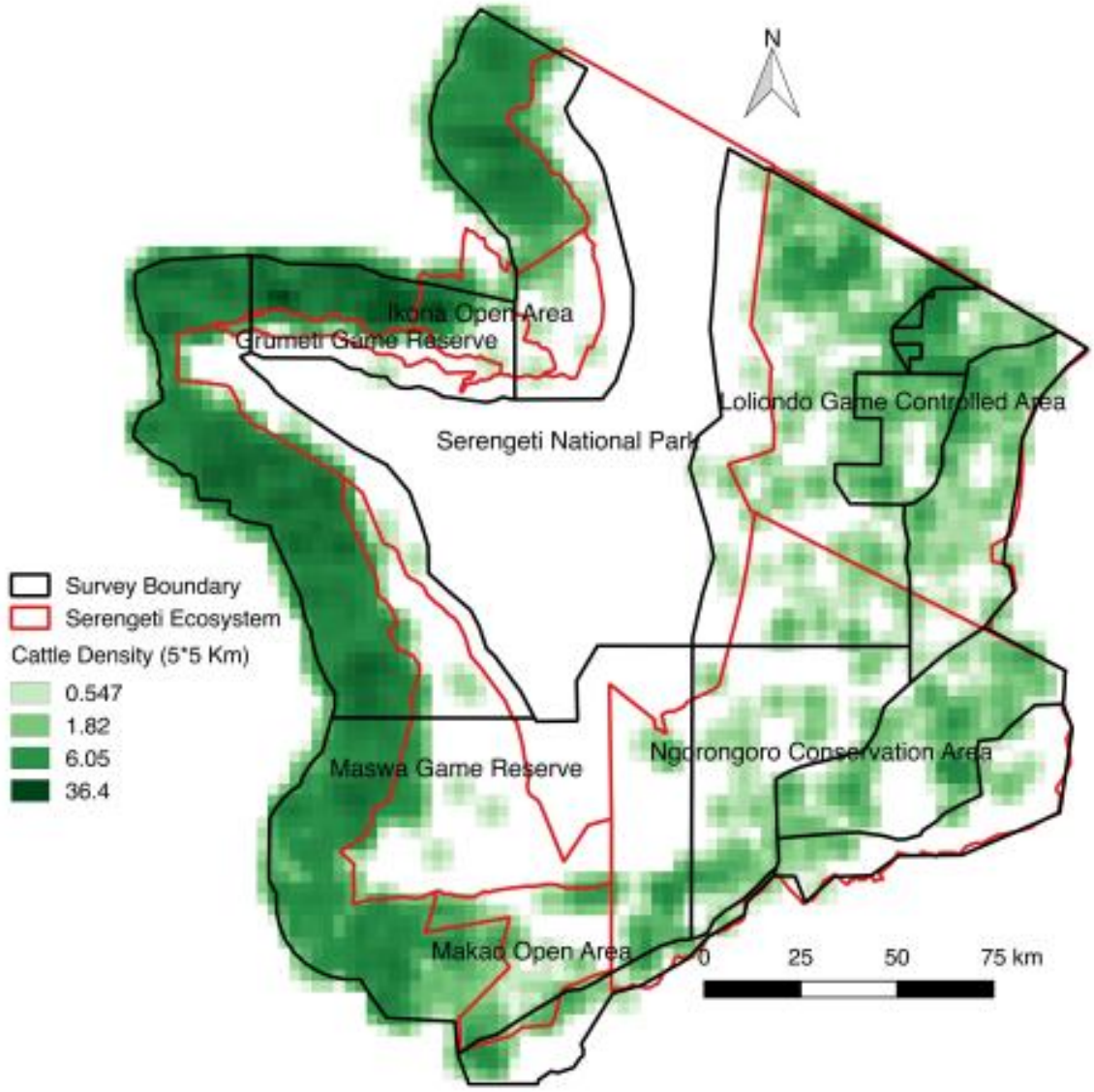

Figure 6: Cattle density and distribution

4.2.2 Shoats

The population of shoats was estimated to be 981,723 ±59,726 whereby Serengeti National Park has an estimate of 33,034 ±16,053 about 3.1%, Ngorongoro Conservation Area with an estimate of 181,281 ±23,947 about 19%, Maswa GR with an estimate of 5,225 ±1,985 about 0.5%, Ikorongo GR with an estimate of 2,178 ±1,176 about 0.1%, Grumeti GR with an estimate of 1,523 ±800 about 0.15%; and Loliondo GCA with an estimate of 238,123 ±45,195 about 24.5%. Similarly to cattle shoats were distributed all over outside the protected area with the highest density record along the North West and Southern parts of the surveyed area (Figure 7).

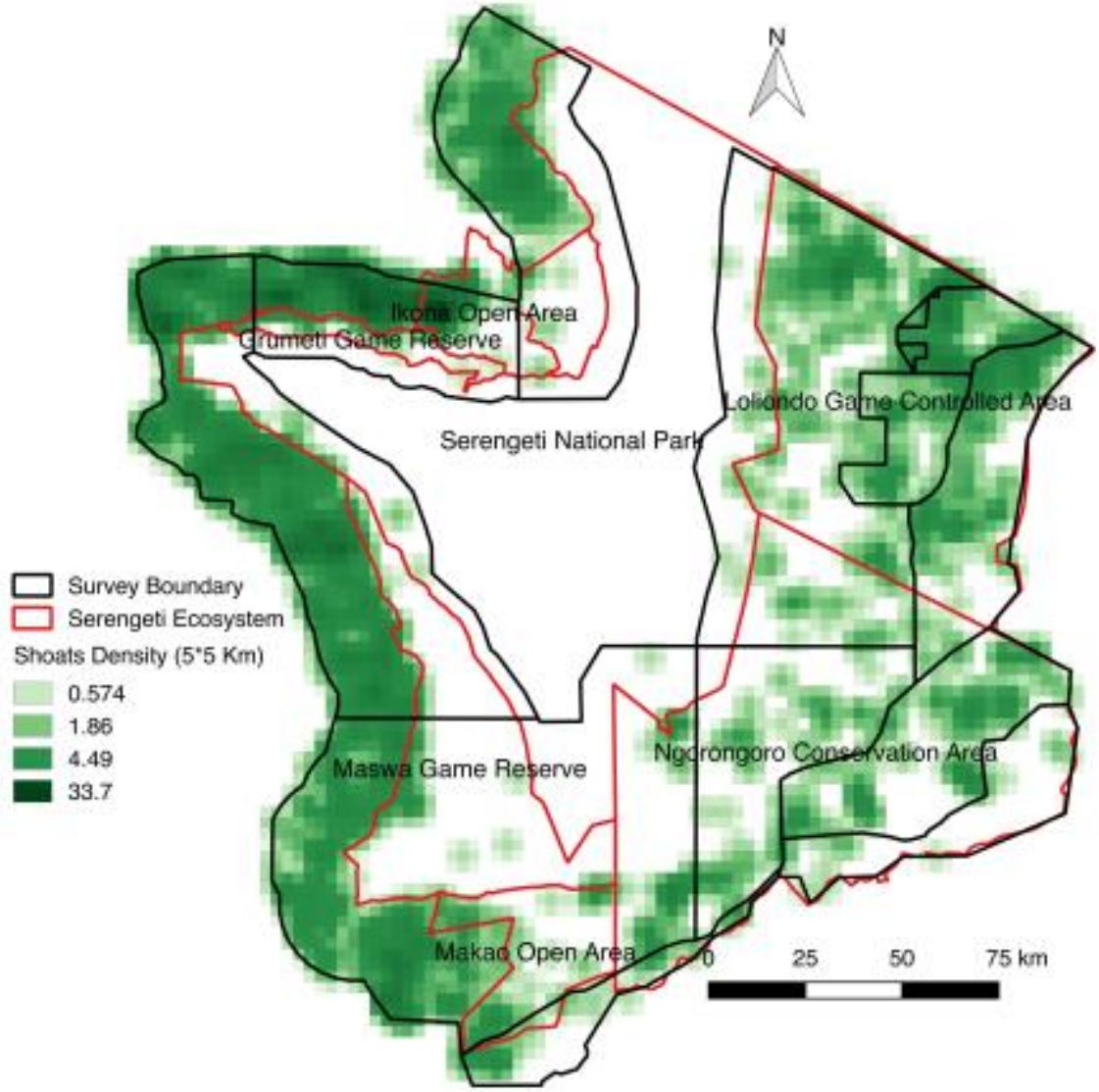

Figure 7: Distribution and density of shoats

4.2.3 Donkey

A total of 1,593 ± 412 donkeys were estimated in the entire censuses zone (Table 3). Donkey were distributed almost everywhere outside the protected area in the Northern, Western and South West of the Serengeti National Park; within Ngorongoro Conservation Area and Loliondo GCA (Figure 8).

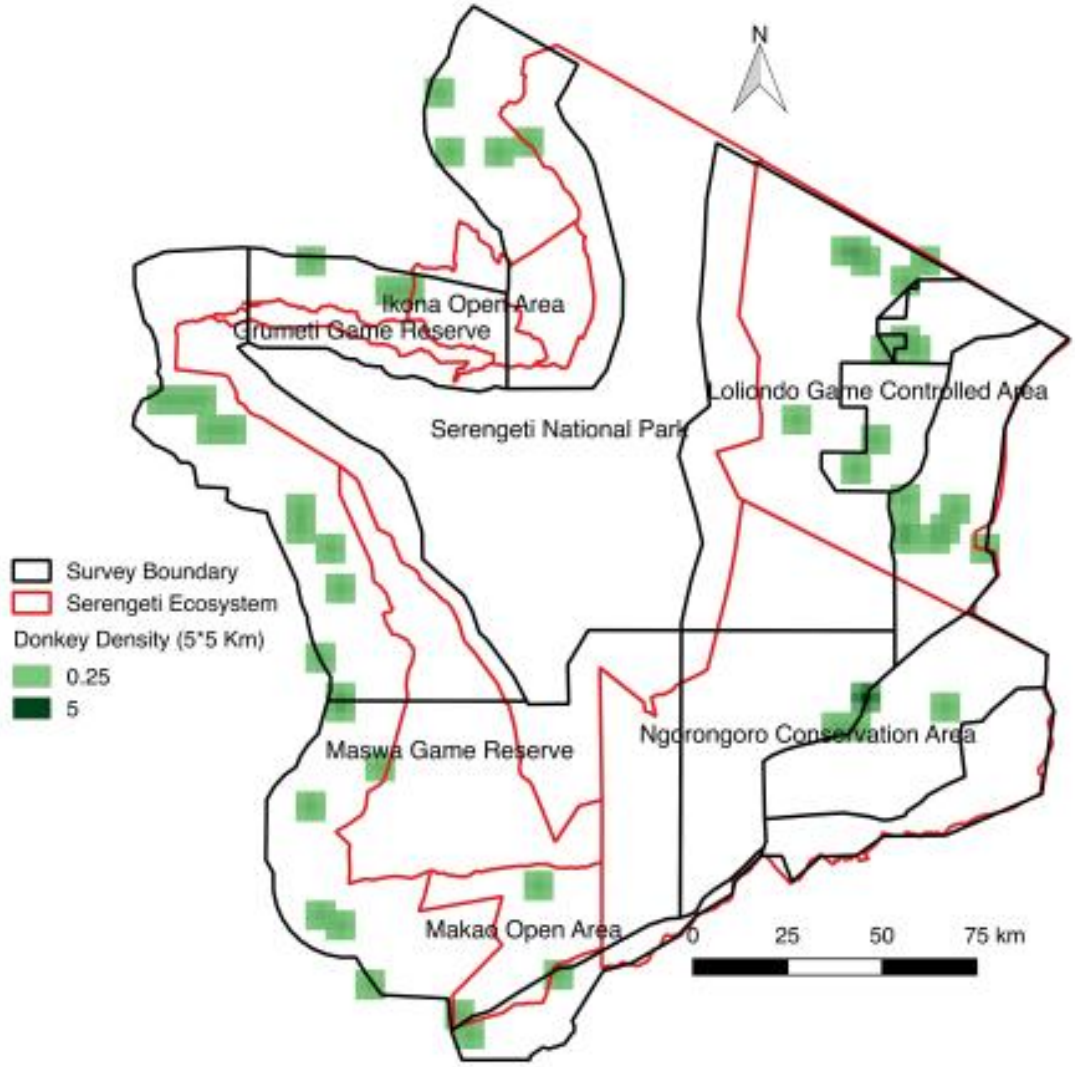

Figure 8: Donkey density and distribution

4.2.4 Camel

Camel was the least recorded livestock in the survey zone. The species was not common probably as it has only recently been introduced in the area – however, given the scattered nature of camel groups and their uniform, more cryptic colouration; they may have been missed or misidentified in images. Only seven observations were recorded in the entire surveyed area. The species was spotted at Grumeti GR and IKONA WMA, Western Serengeti and Loliondo GCA (Figure 9).

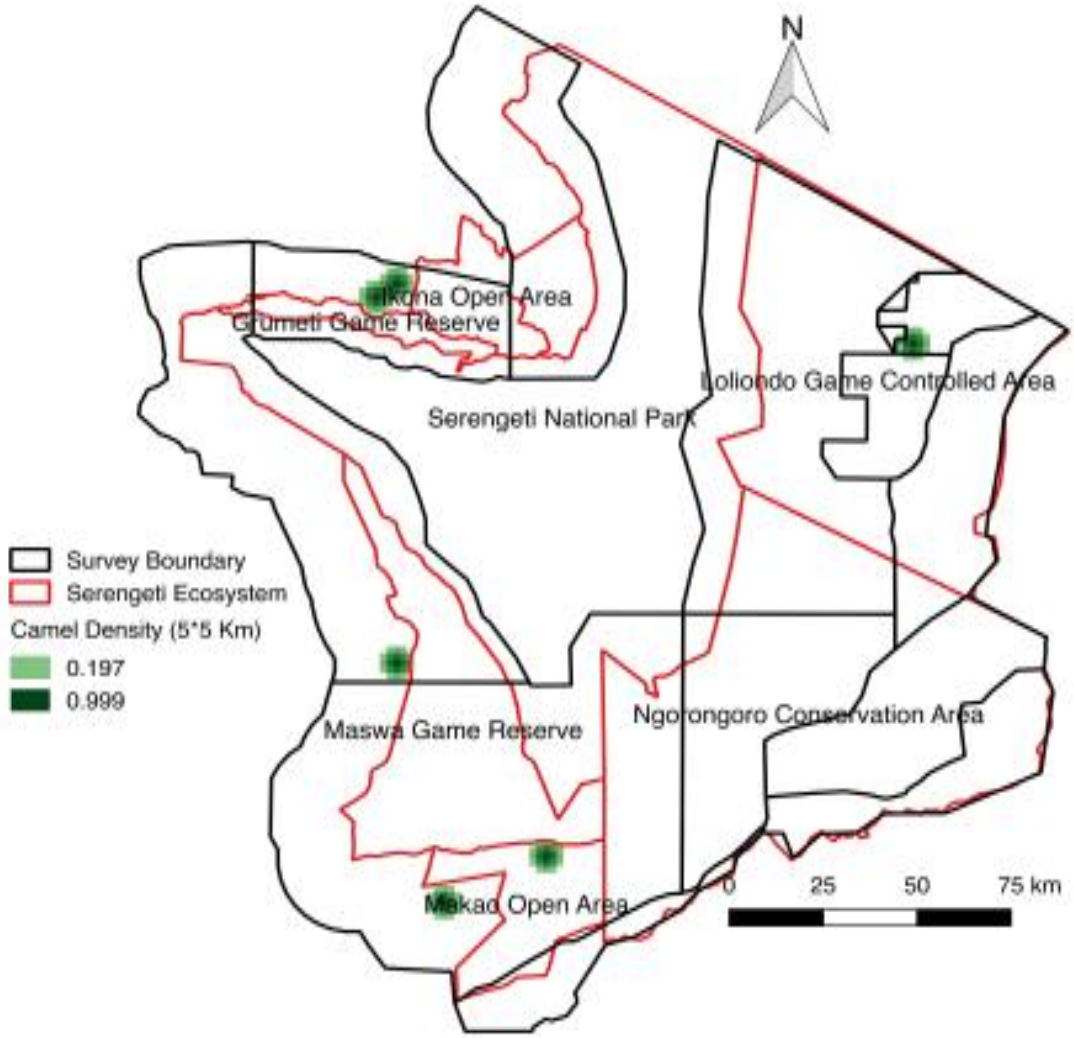

Figure 9: Camel density and distribution

4.2.5 Settlements and Bomas

Estimated number of settlements in the protected areas is 8,680 ±452, bomas with an estimate of 12,072 ±562

Bomas are difficult to estimate: each photograph only indicated presence or absence thus could represent a single boma, a partial boma, or multiple bomas. Estimates are presented here for illustrative purposes only but are useful for relative comparisons – it is likely that the estimates are strong undercounts. Future analyses should use area-measurement methods from photographs.

A total of 53,044 ±1,238 Bomas were estimated over the entire surveyed area (Table 3). All protected areas had a total estimate of 12,072 ±562, Bomas which was 23% of the total bomas in

the entire surveyed area. The estimated number of Bomas in National Parks and Game Reserves are not allowed was 994 ±308. Bomas were distributed all over outside the protected area with the highest density recorded along the North West, Eastern and North Eastern parts of the surveyed area (Figure 10).

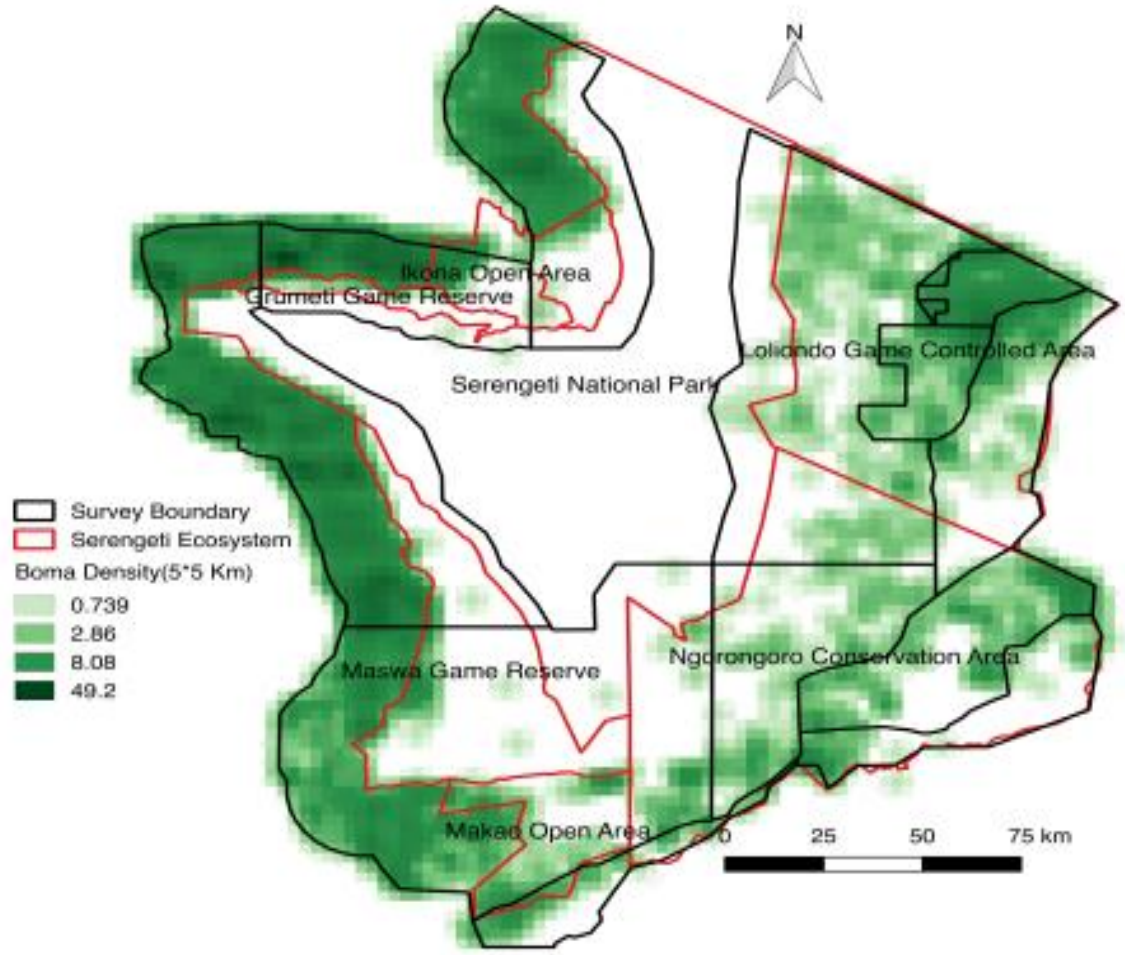

Figure 10: Boma density and distribution

5. DISCUSSION

The survey aimed to provide data for human-wildlife interactions in the Serengeti Ecosystem. This survey focused on wildlife, livestock and human habitation (temporary and permanent) in protected and adjacent areas. The results clearly indicated two levels of interaction between wildlife and livestock. In the western part of the ecosystem, there is semi-interaction that is livestock are interacting with wildlife at the edge of protected areas while in the eastern part of the Serengeti, livestock interact with wildlife within the protected areas (NCA and Loliondo GCA) i.e., total interaction. The two levels of interaction are the results of existing or existed laws that limited/allowed direct interaction. While pastoralism was thought to co-exist with wildlife conservation, it is increasingly become a threat with increases the livestock population size as well as shifting from large to small stock, which are altering the landscape substantially (Randall B et al., 2002). Severe overgrazing has converted large tracts of pasture into bare land, leading to bush encroachment and spreading of invasive plants, thus reducing the overall grazing carrying capacity particularly in Loliondo, Ngorongoro District (ibid, 2002) and the zones in the Ngorongoro Conservation Area where grazing is allowed. Increasing livestock also affects the livelihoods of pastoral communities as the herds exceed carrying capacity of the land and the livestock become more susceptible to climate shifts and drought (ibid, 2002). The result shows that the ecosystem and part of the neighbouring districts have about 1.21 million cattle and ~1 million shoats. The census covered an area of about 3% of the area of Tanzania and holds 5% of the cattle and 6% of the country shoats (goats and sheep). Currently, Tanzania is estimated to have 25m cattle projected from the estimates of 23m (NBS, 2012) at a growth rate of 2.4% annually.

This method presents an interesting chance to examine the relative numbers of reported livestock from the 2012 census compared to estimates from aerial survey. However, the 2012 census does not report individual Districts, and the regional areas reported differ from the map areas available for this analysis. A future analysis should involve a comparison made by Districts

Cattle in protected areas in the greater Serengeti Ecosystem are legally allowed in NCA and still contentious in Loliondo GCA as the wildlife Act of 2009 allow grazing under the permission of the Director of Wildlife but prohibited in National Parks and Game Reserves. Large proportions of

cattle inside National Park and Game Reserves were estimated in Bariadi districts while large concentration of cattle (density) in prohibited area were estimated in Tarime and Bunda districts (Figure 11).

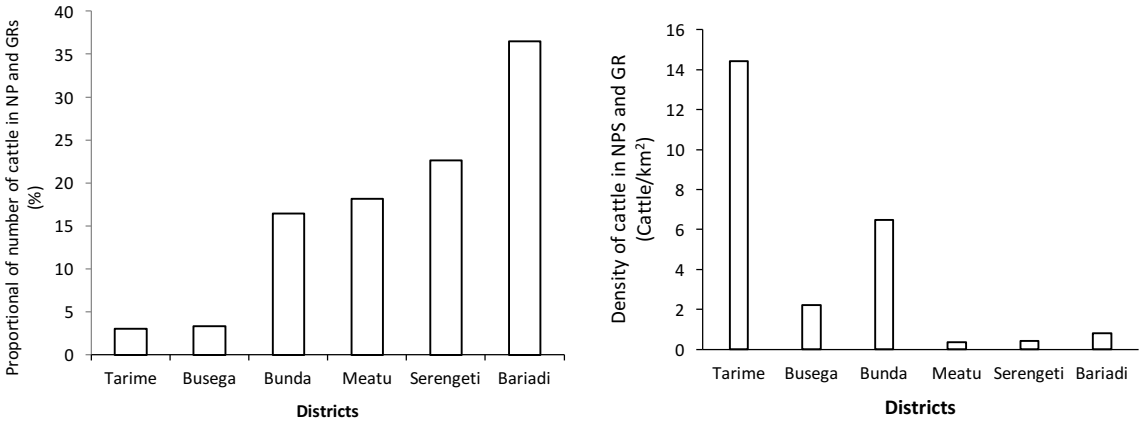

Figure 11: (a) Percentage of cattle found in prohibited protected area per district; (b) density of cattle in protected area per district.

Serengeti, Meatu, Bunda and Bariadi districts have the largest proportion of livestock in the ecosystem, posing pressure on the Game Reserves and National Park. Ngorongoro District poses a different challenge of carrying capacity in the district; where the majority of the cattle are roaming within the wildlife conservation area namely GCA and NCA but also in the fringes of the Serengeti National Park on the east. The free movement of cattle in the Loliondo GCA and NCA needs check and balance that will support their rangeland management programme so as to reduce the encroachment in to the game reserve and national park.

Bomas and settlements: The presence of settlements and bomas in protected areas in NCA and Loliondo need certain permission to exist so as to limit where and when the bomas can be build. Bomas in Parks and Game Reserves are strictly prohibited yet were observed to be numerous along the boundary areas; for SNP it was becoming common in the Loliondo side (Figure 10). Generally, NCA and Loliondo may affect wildlife conservation if the increase of bomas and settlement remained unchecked. Lack of controlled habitation of any kind compromises long-term conservation strategies.

6. ACKNOWLEDGEMENTS

We are grateful to the Wildlife Division (WD), Tanzania National Parks (TANAPA) and Ngorongoro Conservation Area Authority (NCAA) for permission to conduct the survey and for providing aircrafts, personnel and logistical support. Financial support from KfW through FZS and NCAA is highly acknowledged. Special thanks should go to the survey crew and to all who provided assistance in the field.

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Randall B. Boone, Michael B. Coughenour, Kathleen A. Galvin_,y and James E. Ellis Addressing Management questions for Ngorongoro Conservation Area,Tanzania, using the Savanna modelling system

8. APPENDICES

8.1 Appendix I: List of flying crews of the 2016 dry season aerial census of the Serengeti Ecosystem.

AIRCRAFT	5H-MPK (WD)	5H-SNP (TANAPA)	5H-ZGF (FZS)
Pilot	W. Minja (WD)	B. Kessy (TANAPA)	B. Shayo
FSO	E. Lyimo (TAWIRI)	J. Sanare (TAWIRI)	M.Mwita

8.2 Appendix II. List of ground crew participation for the 2016 dry season aerial census of Serengeti ecosystem

Scientific Supervision	Dr. Simon Mduma (TAWIRI)
Field Supervision	Dr. Edward Kohi (TAWIRI)
Logistics and Coordination	H. Maliti (TAWIRI)
Survey Technical Advisor	H. Frederick (FZS)
Data entry	S. Bakari, G. Mwakalebe, M. Machoke, E. Lyimo, J. Sanare (TAWIRI) P. Chacha (NCAA) and A. Migezo (WD)
Validation and Verification	Dr. S. Mduma, Dr. E. Kohi , H. Maliti, M. Machoke (TAWIRI) and H. Frederick (FZS)
Data analysis	M. Machoke and H. Frederick (FZS)
Mapping & geo-referencing	J. Sanare, and M. Machoke (TAWIRI)
Report writing:	Dr. S. Mduma, Dr. E. Kohi, H. Maliti, M. Machoke, S. Bakari, C. Leweri, E. Lyimo and J. Sanare (TAWIRI), and H. Frederick (FZS)
Report layout and production	H. Mkwizu (TAWIRI)

8.3 Jolly method II

The calculation of $\hat{Y}$ and 95% confidence limits of $\hat{Y}$ using Jolly's Method 2 for unequal sampling units:

Let N = the number of sample units in the population;

n = the number of sample units in the sample;

Z = the area of the census zone;

y = the number of animals counted in that unit;

$\hat{R}$= the ratio of animals counted to area searched = $\sum y / \sum z$

(1) s_y^2= the variance between animals counted in all the units

$= \frac{1}{n-1} \cdot \left(\sum y^2 - \frac{(\sum y)^2}{n} \right)$

(2) s_z^2= the variance between animals counted in all the units

$= \frac{1}{n-1} \cdot \left(\sum z^2 - \frac{(\sum z)^2}{n} \right)$

(3) s_z^2= the covariance between the animals counted and the area of each unit

$= \frac{1}{n-1} \cdot \left(\sum zy - \frac{(\sum z \cdot \sum y)}{n} \right)$

Then, population total $\hat{Y} = Z \cdot \hat{R}$

Population variance $Var(\hat{Y}) = N \frac{(N-n)}{n} \cdot \left(s_y^2 - 2 \cdot \hat{R} \cdot s_{zy} + \hat{R}^2 \cdot s_z^2 \right)$

Population standard error $SE(\hat{Y}) = \sqrt{Var(\hat{Y})}$

95% confidence limits of $\hat{Y} = \mp t \cdot SE(\hat{Y})$

(where 't' is for n-1 degrees of freedom).