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# AERIAL POINT SURVEY OF WILDEBEEST IN THE GREATER SERENGETI ECOSYSTEM-WET SEASON 2023

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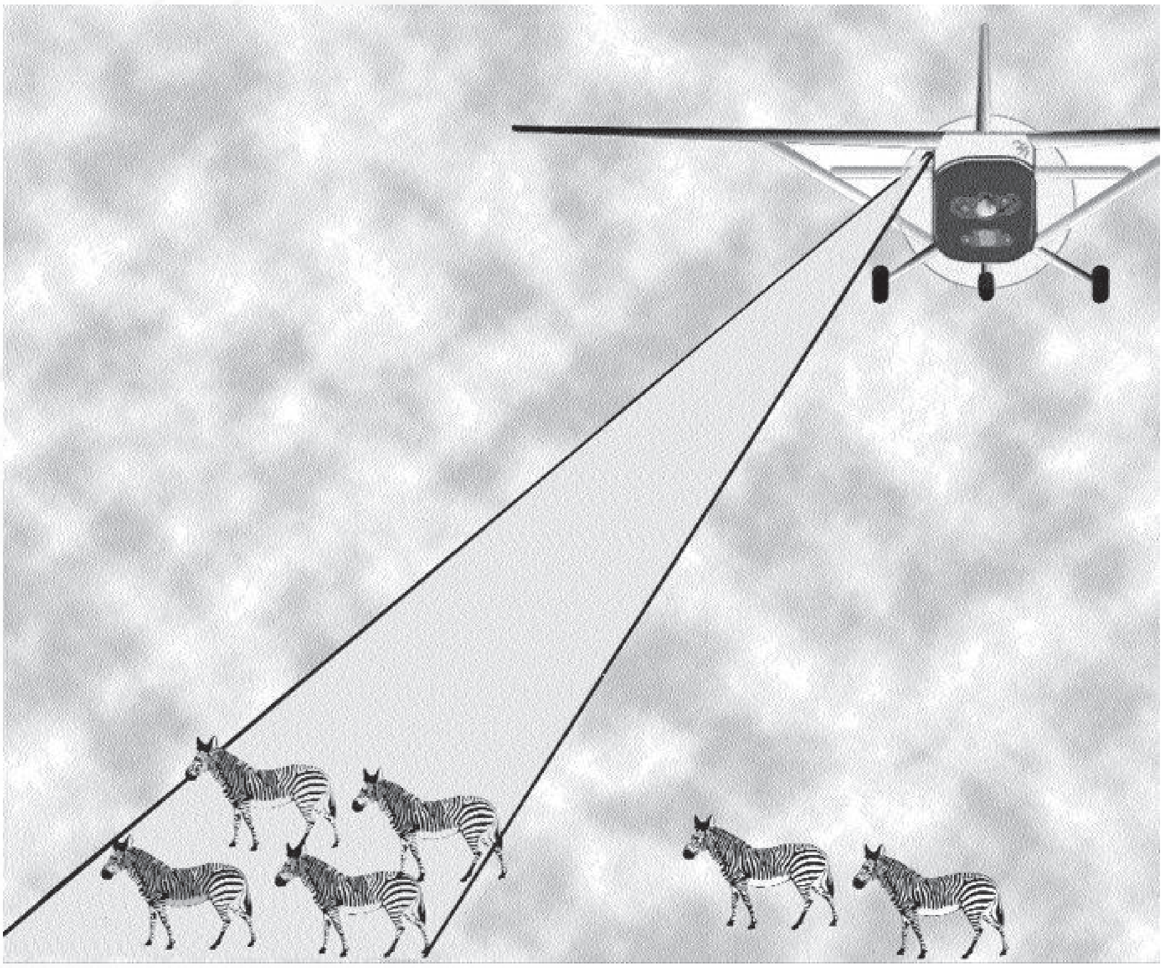

Conducted by

**Tanzania Wildlife Research Institute**

## COOPERATION AND COLLABORATION

The successful implementation of the migratory wildebeest aerial census survey 2023 was made possible thorough planning, hard work, and good collaboration between Tanzania Wildlife Research Institute (TAWIRI), Tanzania National Parks, Frankfurt Zoological Society (FZS) with funding from the German Government through KfW Development Bank under the Serengeti Ecosystem Development and Conservation Project (SEDCP), the University of Glasgow (Serengeti Biodiversity Programme) and TAWIRI.

| | | |
|---|---|---|
| | TANZANIA NATIONAL PARKS<br>P. O. Box 3134, Arusha<br>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<br>Dar-es-Salaam Road<br>Kingolwira Area<br>P. O. Box 2658, Morogoro<br>Email: cc@tawa.go.tz | Tanzania Wildlife Management Authority (TAWA) was established by Ministerial order in 2014 to sustainably conserve and utilise wildlife resources in Game Reserves, Game Controlled Areas and Open Areas. |
| | NGORONGORO CONSERVATION AREA AUTHORITY<br>P. O. Box 1<br>Ngorongoro Crater, Tanzania<br>Email: conservator@ngorongorocrater.go.tz | Ngorongoro Conservation Area Authority (NCAA) was designated a Conservation Area as far back as 1959 as an Authority entrusted with the management of NCA. The key roles are to conserve nature and cultural resources available, develop and promote tourism in the area, as well as improve the welfare of indigenous communities. |
| | FRANKFURT ZOOLOGICAL SOCIETY<br>P.O Box 14935<br>Arusha, Tanzania<br>Email: info@fzs.org | Frankfurt Zoological Society (FZS) is an international NGO that has been working to conserve wildlife and ecosystems in Tanzania since 1959. |
| | KfW Office Dar es Salaam<br>Rufiji Street Plot 1668<br>House No. 20<br>Masaki Peninsula<br>Dar es Salaam, Tanzania<br>Email: kfw.daressalaam@kfw.de | KfW Development Bank funds development cooperation worldwide on behalf of the German Federal Ministry for Economic Cooperation and Development. Germany is the biggest bilateral donor in the sector of biodiversity in Tanzania |
| | University of Glasgow<br>Glasgow, G12 8QQ<br>Scotland, UK<br>admissions@glasgow.ac.uk | The University of Glasgow the fourth oldest university in the English-speaking world, founded in 1451 and is classified as one of the world's top 100 universities. The University supports extensive collaborative research and training in Tanzania |

## EXECUTIVE SUMMARY

This report presents the findings of the 2023 wildebeest herd population estimation in the Greater Serengeti Ecosystem (GSE). The main objective of this study was to determine the abundance of the wildebeest population using the Aerial Point Sampling (APS) method, which involves conducting aerial transects over the herds and collecting population data through aerial photographs. The survey was undertaken end of March (most of the wildebeest inhabit the short grass plains located in the southeastern part of the Serengeti and the Ngorongoro Conservation Area, before the migration transitions towards the woodland regions of the western Serengeti). The wildebeest count survey holds significant ecological importance, as they serve as a keystone species in the GSE. They are important in shaping the region's biodiversity and maintaining the overall balance of the ecosystem. Consequently, understanding their population dynamics and estimating their numbers is important for devising effective conservation and management strategies.

The implementation of the APS method in combination with trained TAWIRI volunteer (counters) has been demonstrated as a labour-intensive, yet highly cost-effective approach for estimating wildebeest populations. During the 2023 wildebeest count, the complete set of survey images was precisely processed, resulting in an estimated population size of **1,366,109 ± 231,741** SE. The approach involved the efforts of 12 dedicated volunteer counters who meticulously counted each image three times, and the entire counting process spanned approximately 30 days. To obtain a reliable population estimate, raw counts underwent rigorous filtering and the removal of extreme values. Through this process, a meaningful and reliable estimate of the population was derived, contributing valuable insights for wildlife conservation and management. Despite the labour-intensive nature of the APS method and volunteer-based counting, the benefits are significant. The involvement of trained volunteers not only minimized the costs associated with professional expertise but also expedited the data collection process. By counting each image thrice, the volunteers ensured a high level of accuracy, reducing potential counting errors and enhancing the reliability of the final estimate.

The conclusions drawn from this survey underscore the potential of utilizing the APS method in conjunction with volunteer counting to achieve rapid and cost-effective population estimates for wildebeests. However, it is crucial to exercise caution, as there is a need for further improvement in accuracy to ensure reliable results. To address this, some recommendations have been proposed, including the exploration and refinement of automated computer-counting method (Machine learning). By validating the results and continuously improving the counting protocols, the reliability of future surveys can be enhanced significantly. Despite the current method's limitations, this survey has provided invaluable insights into the population dynamics within the ecosystem. Moreover, it highlights the dedication and commitment of volunteers towards ecological conservation. The findings from this survey contribute significantly to ongoing efforts aimed at conserving and managing the wildebeest population, ensuring the long-term ecological integrity and sustainability of the Serengeti ecosystem. By incorporating the recommendations and building upon the successes of this study, wildlife management strategies can be strengthened and informed by more reliable population estimates.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| APS | Aerial Point Survey |
| FZS | Frankfurt Zoological Society |
| GPS | Global Positioning System |
| GSE | Greater Serengeti Ecosystem |
| GSME | Greater Serengeti Mara Ecosystem |
| PGR | Pololeti Game Reserve |
| NCAA | Ngorongoro Conservation Area Authority |
| SEDCP | Serengeti Ecosystem Development and Conservation Project |
| SENAPA | Serengeti National Park |
| TANAPA | Tanzania National Parks |
| TAWA | Tanzania Wildlife Management Authority |
| TAWIRI | Tanzania Wildlife Research Institute |
| UTC | Universal Transverse Mercator |
| WCS | Wildlife Conservation Society |
| WMA | Wildlife Management Area |

# 1.0. INTRODUCTION

Common wildebeests (*Connochaetes taurinus*) are large herbivorous mammals that belong to the bovid family. They are native to the grasslands and savannas of eastern and southern Africa, with a significant population residing in Tanzania's Greater Serengeti Ecosystem (GSE). Common wildebeests are characterised by their robust build, shaggy mane, and distinctively curved horns (Leuthold 2012, Estes 2014). The wildebeest population in the GSE is of ecological and socio-economic importance. They form the largest migratory (Great Wildebeest Migration) ungulate population in the world, making them an important component of the region's biodiversity (Torney *et al*. 2018). Their large numbers and migratory behaviour have profound ecological implications. They play an important role in shaping the dynamics of the Serengeti ecosystem through their influence on vegetation through grazing, trampling, and nutrient cycling (McNaughton *et al*. 1988, Pastor *et al*. 2006, Hempson *et al*. 2015, Sitters and Andriuzzi 2019). Their selective feeding habits shape the composition and structure of the grasslands, woodlands, and shrublands, creating diverse habitats for other plant and animal species (Sinclair 2003, Anderson *et al*. 2008, Blair *et al*. 2014). Their movements create dynamic interactions with other herbivores, such as zebras and gazelles, as they share grazing areas and water sources (McNaughton and Georgiadis 1986, Nelson 2012, Hopcraft *et al*. 2014). This interplay of species influences competition for resources and shapes coexistence strategies among wildlife in the ecosystem.

Wildebeest are also integral to the predator-prey dynamics in the ecosystem. Their large population size not only shapes the vegetation structure and composition through their feeding habits but also provides food source for predators, including lions, hyenas, and crocodiles (Curio 2012, Ngana *et al*. 2014, Dannock 2016). The wildebeest migration acts as a focal point for predator activity, resulting in awe-inspiring predator-prey interactions and a complex web of trophic relationships. In addition to their ecological importance, wildebeest also act as seed dispersers, aiding in the regeneration and diversity of plant species as they move across the ecosystem (Anderson *et al*. 2014, Bro-Jørgensen 2016). This process helps maintain the diversity and regeneration of vegetation communities. Beyond their ecological roles, wildebeest hold cultural and economic significance. In addition, the annual Great Wildebeest Migration is a globally recognised phenomenon that attracts tourists worldwide (Kaltenborn *et al*. 2011, Menge *et al*. 2022). This spectacle supports local livelihoods and raises awareness about the importance of conserving the GSE as a natural heritage site.

The GSE in Tanzania encompasses the Serengeti National Park and the adjoining Ngorongoro Conservation Area, Maswa Game Reserve, Grumeti-Ikorongoro Game Reserves, Pololeti Game Reserve, Ikona and Makao Wildlife Management Areas (WMA). On the Kenya side, the GSE encompasses the Masai Mara National Reserve and the wildlife conservancies to the north and east of the reserve. This landscape spans approximately 30,000 km$^2$ and hosts number of wildlife species. However, wildebeest stands out as one of this unique ecosystem's most prominent and influential inhabitants (Estes 2014, Hopcraft *et al*. 2015). The population of wildebeest in the ecosystem undergone remarkable changes since the mid-20th century. The population followed a specific pattern over the years. From 1963 to 1977, their numbers went up. Then, there was a stable period from 1977 to 1993, where the population remained fairly constant. However, there was a decline in the wildebeest population during the drought that occurred in 1993 and 1994. (Mduma *et al.* 1999). In 1955, there were approximately 190,000 wildebeests. But through the dedicated conservation efforts, including vaccinating livestock against rinderpest in 1958, which removed the threat of rinderpest from the ecosystem and allowed wildebeest numbers to grow, their population has now risen significantly to around 1.3 million (Hopcraft *et al*. 2015). This number has captured the attention of researchers and conservationists emphasising the need for reliable population assessments to understand the ecological implications.

The importance of counting wildebeest to monitor their population growth, distribution patterns and conservation status to ensure their long-term survival cannot be overstated. In response to the above, aerial surveys have emerged as an indispensable approach for estimating wildlife population numbers, including wildebeest (Torney *et al*. 2019). These are invaluable for assessing the effectiveness of conservation measures and informing management decisions to ensure the long-term sustainability of the wildebeest population and the ecosystem at large. These surveys involve using light-winged aircraft flying systematic transects, counting and/or capturing high-resolution aerial photographs (Talbot and Stewart 1964, Estes and East 2009). Aerial wildebeest surveys have been conducted on a 2–3-year cycle and the current one marks a significant milestone as the 25$^{th}$ such survey conducted.

## 1.1. Rationale for wildebeest survey

Undertaking wildebeest survey has several ecological, socio-economic, and scientific justifications. It is important in conservation efforts, understanding ecosystem dynamics, monitoring biodiversity, promoting sustainable tourism, and facilitating scientific research. It also serves as a tool in preserving the unique natural heritage of the ecosystem and ensuring the long-term well-being of its wildlife and ecosystem. Undertaking the wildebeest survey has the following importance;

**Conservation and Management:** The GSE is a globally significant conservation area, and wildebeest are a keystone species within this ecosystem. Conducting such a survey helps assess the population size, distribution, and trends, which are crucial for effective conservation and management strategies. It enables conservationists to monitor the status of the wildebeest population, identify potential threats, and implement appropriate measures to ensure their long-term survival (Thirgood *et al*. 2004, Kideghesho *et al*. 2006, Msoffe *et al*. 2019).

**Keystone Species/Ecosystem Dynamics:** Wildebeest are a keystone species in the Serengeti ecosystem. They profoundly impact vegetation, nutrient cycling, and overall ecosystem dynamics through their grazing patterns and annual migration. Surveying wildebeest helps monitor their population, distribution, and behaviour, providing insights into the functioning of the ecosystem and facilitating effective conservation strategies (Pirot *et al*. 2000, Hughes 2009).

**Monitoring Biodiversity:** The GSE is renowned for its exceptional biodiversity, and the wildebeest survey contributes to monitoring and assessing the overall status of this ecosystem. Changes in wildebeest populations can indicate shifts in habitat quality, availability of resources, and interactions with other species. By monitoring the wildebeest, conservationists can gather valuable data on ecosystem health, identify potential ecological imbalances, and take proactive measures to protect the diverse flora and fauna.

**Tourism and Economic Benefits:** The wildebeest migration is a world-famous wildlife spectacle and a major tourist attraction (Kaltenborn *et al*. 2011). Undertaking a wildebeest survey helps manage tourist activities, ensuring sustainable tourism practices that minimise disturbances to the wildebeest and their habitat. This protects the natural heritage and contributes to the national and local economy through revenue generation, employment opportunities, and community development.

**Livelihoods and Cultural Heritage:** The Serengeti ecosystem supports local communities whose livelihoods are intricately linked to the sustainable use of natural resources. Monitoring wildebeest populations and their habitats helps ensure the long-term viability of the ecosystem, thus fostering sustainable development and preserving cultural heritage associated with wildlife.

**Scientific Research and Education:** The wildebeest survey provides valuable data for scientific research, enabling scientists/researchers to study various aspects of wildebeest biology, behaviour, and ecological interactions. The survey data can advance conservation science, understanding species adaptations, migration patterns, and responses to environmental changes. Furthermore, the knowledge gained through research can be used to inform management decisions and disseminated to educate the public and raise awareness on wildlife conservation (Robinson *et al*. 2012).

## 1.2. Survey objectives

This survey aimed to determine the abundance of wildebeest in the ecosystem to monitor population trends and helps estimate recruitment, mortality, immigration, and emigration. Specifically, it aimed at establishing recent population estimates and distribution of wildebeests in the GSE, specifically in the plains.

## 1.3. Main features of the Serengeti migratory wildebeests

**(i) Largest Single Herd of Migratory Ungulates:** Serengeti wildebeests form the largest single herd of migratory ungulates worldwide (Hopcraft *et al*. 2015). Their massive numbers create a wonderful-inspiring spectacle as thousands gather and move together through different terrains and habitats in the Serengeti ecosystem, including grasslands, plains, woodlands, and river crossings (Mahony 2020).

**(ii) Annual Migration Driven by Green Pastures and Rainfall:** The wildebeest's annual migratory system is influenced by the availability of green pastures determined by rainfall patterns (Anderson *et al*. 2016). They undertake an annual cyclical journey of around 800 km (Kennedy and Kennedy 2013) in search of abundant grazing opportunities however most animals travel about 2500km in a year, following the seasonal changes in vegetation conditions (Hopcraft *et al*. 2014, Hopcraft *et al*. 2015, Subalusky *et al*. 2017).

**(iii) Boundary Definers of the Serengeti Ecosystem:** The migrating wildebeest herds play a significant role in defining the boundaries of the GSME. This ecosystem includes several protected areas such as Serengeti National Park, Ngorongoro Conservation Area, Ikorongo-Grumeti Game Reserves, Maswa Game Reserves, Ikona and Makao Wildlife Management Areas in Tanzania, and Masai-Mara Game Reserves in Kenya. The migration extends beyond these protected areas, reaching into the unprotected western part of the ecosystem and interactions with human activity.

**(iv) Congregation on Serengeti Short Grass Plains:** During the wet season, the wildebeest herds congregate on the Serengeti's short grass plains (Fig. 1). These plains provide favourable conditions for grazing, calving, and reproductive activities (Estes 2014). The wildebeests take advantage of the abundant food resources and the protective cover offered by the short grass, ensuring the survival of their young and the continuity of their population (Morrison and Bolger 2012, Hopcraft *et al*. 2015, Veldhuis *et al*. 2019).

## 2.0. SURVEY AREA, MATERIALS AND METHODS

### 2.1. Survey area

The Serengeti ecosystem, spanning an area of 25,000 km², is in Northern Tanzania and southern Kenya (includes the Masai Mara National Reserve), between 34° and 36° Longitude and 1° 30' to 3° 30' Latitude. The area covers the eastern Serengeti National Park (SENAPA), north of Ngorongoro Conservation Area (NCA) and Pololeti Game Reserve as well part of Loliondo open areas (Fig. 2.1). It is renowned for its vast expanse and rich biodiversity, attracting visitors worldwide. One of the notable features of the ecosystem is its large migratory herds. These include wildebeests (*Connochaetes taurinus*), zebras (*Equus burchelii*), and various species of gazelles (Sinclair and Arcese 1995, Kideghesho *et al.* 2007). These herds undertake epic annual migrations, captivating observers with mass movements across the plains.

In addition to the migratory herbivores, the ecosystem supports a diverse range of large herbivore species such as the African elephant (*Loxodonta africana*), African buffalo (*Syncerus caffer*), Cape eland (*Taurotragus oryx*), Coke's hartebeest (*Alcephalus buselaphus cokii*), impala (*Aepyceros melampus*), giraffe (*Giraffa camelopardalis*), black rhinoceros (*Diceros bicornis*), hippopotamus (*Hippopotamus amphibius*), and Grant's gazelle (*Gazella grantii*) and a variety of carnivores such as; leopard (*Panthera pardus*), lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), black-backed jackal (*Canis mesomelas*), wild dog (*Lycaon pictus*), and spotted hyena (*Crocuta crocuta*). Both herbivores and carnivores play a crucial role in shaping the ecosystem through their grazing patterns and interactions with other species and in maintaining the balance of the ecosystem by regulating prey populations and contributing to nutrient cycling.

The climate in the ecosystem is characterised by distinct wet and dry seasons. The wet season typically occurs from November to May, with the peak rainfall experienced between March and May, with an average annual rainfall ranging from 500 to 1,200 mm (20 to 47 inches). In contrast, the dry season prevails from June to October, with lower rainfall and drier conditions. The average monthly rainfall during this period drops significantly, ranging from 25 to 75 millimetres (1 to 3 inches). The dry season brings about a scarcity of water and vegetation, resulting in increased competition among herbivores for limited resources. The availability of rainfall is a key driver for the migratory behaviour of wildebeests and other herbivores, as it determines the growth of green pastures that provides food resources and water sources for wildlife.

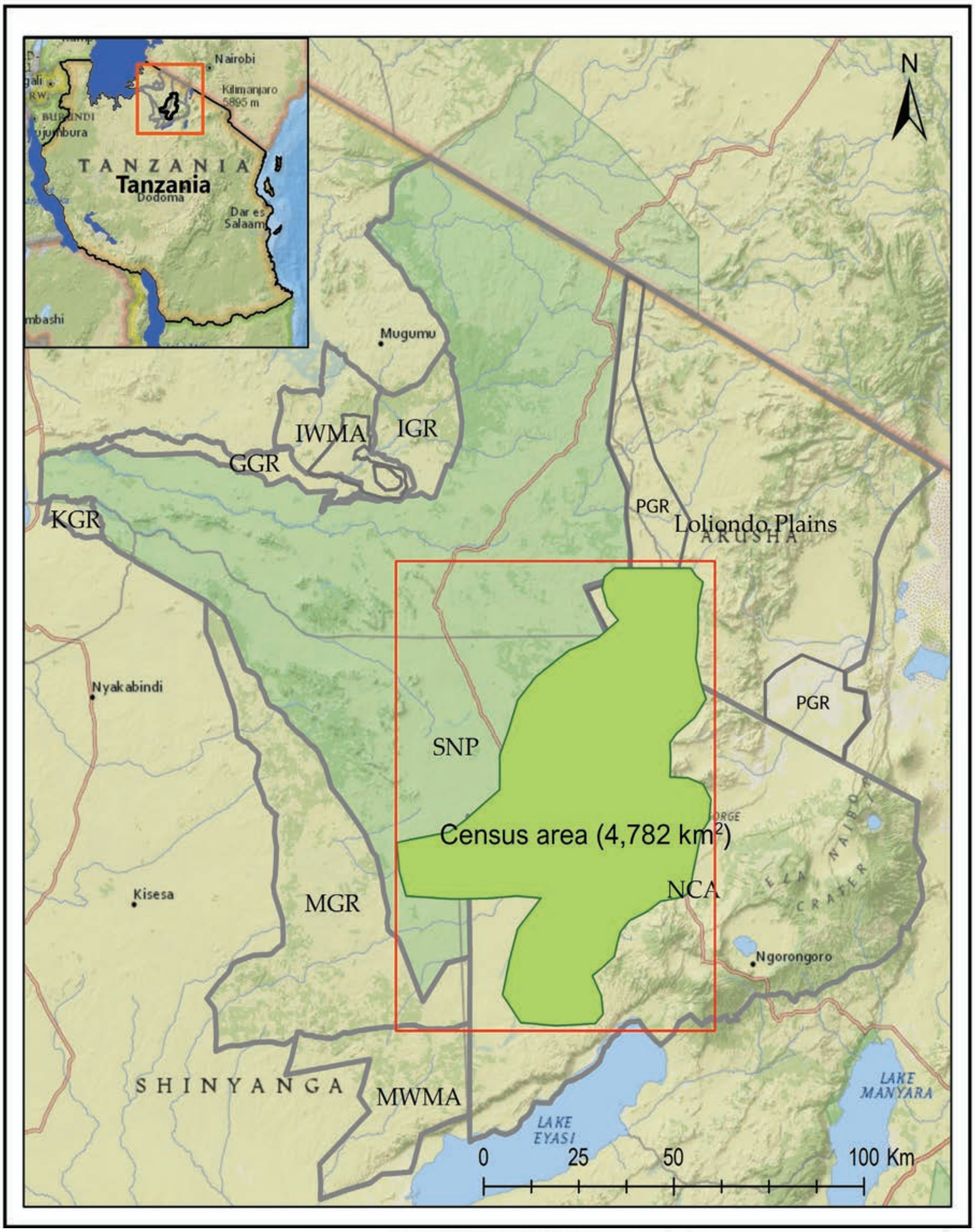


**Figure 2.1**: Map of Serengeti and other protected areas in relation to Tanzania

The ecosystem experiences stable temperatures year-round, with slight variations between the wet and dry seasons, and an average temperature ranging from 20 to 30$^{o}$ C. The ecosystem's soil diversity, influenced by underlying geological formations, includes fertile and well-drained volcanic soils, supporting nutrient-rich grasses that enhance productivity. Additionally, alluvial soils found in flood-prone areas, such as rivers and watercourses, also foster the growth of nutrient-rich riverine vegetation. The ecosystem highlights various vegetation types, including grasslands, woodlands, and riverine forests. The short grass plains thrive during the wet season, while common acacia and mixed savannah woodlands provide shelter and food sources for diverse wildlife. The riverine forests, found along watercourses, play a crucial role in providing essential habitats for various plant and animal species.

## 2.2. Materials and Methods

The Aerial Point Survey (APS) was carried out between the 28th and 31th March 2023 in the GSE using a method described by Norton Griffiths (1978). This time was strategically chosen as it corresponds to the rainy season, where the entire migratory wildebeest herd gathers on the expansive short-grass plains (Fig 3.1). These plains are characterised by minimal tree cover, which provides optimal grazing opportunities generally across the Pololeti Game Reserve, Ngorongoro Conservation Area, and Serengeti National Park. (Fig. 2.1). The survey employed a Cessna Tail dragger 5H-LAB aircraft, owned by FZS, with a flying crew consisting of two individuals and well-calibrated prior to the survey (Fig. 2.1). Flight paths were flown in an east-west direction and placed 2.5 km apart, allowing for wider coverage (Fig. 2.2).

The count only focused on large herds of migratory wildebeests, and the several smaller non-migratory herds of resident wildebeest that choose to remain in their home areas, primarily located in the western corridor near Ndabaka and northern regions in the Masai Mara in Kenya, are usually counted during the Systematic Reconnaissance Flight (SRF) and not included in the APS because they occur at very low densities compared to the migrants, i.e. western corridor (Hopcraft *et al.* 2015). These resident herds have adapted to their local environments and exhibit different movement patterns compared to the larger migratory herd. The restricted counting on specific areas aims to capture an accurate representation of the total migratory population within the Serengeti ecosystem.

### 2.2.1. Photo flights

***Aerial Platform***: The census zone was surveyed using a light winged aircraft (Fig. 3.1).

***Horizontal Navigation***: The survey designs utilized an aviation-grade Global Positioning System (GPS) device, specifically the Garmin Map 296. The survey transects were planned and mapped using ArcGIS software. Subsequently, these planned routes were transferred and uploaded to the GPS device before the aircraft's departure. To ensure data synchronization, a photo of the GPS's clock was taken with the survey camera so we could accurately synchronise the time on the camera with the time on the GPS, set in Coordinated Universal Time (UTC). This synchronisation facilitated precise alignment and referencing of the data streams collected during the survey.

***Vertical navigation:*** During the survey, the GPS was used to estimate the elevation above sea level of the aircraft and then subtracted the elevation of the ground from the Digital Elevation Model (DEM) to calculate the altitude above ground for each photo. The height above ground was manually recorded from the radar altimeter about every 30 seconds and used to compare against the height above ground measured by the GPS. Front seat observer recorded altitude, ensured GPSs are working, helped pilot navigate the transects, monitored the herds and calls beginning and end of transect. Rear seat observer was responsible for monitoring the camera equipment. The GPS altimeter was a much more accurate at high altitudes (i.e. >500 feet). This ensured that the altitude data corresponding to each photograph was documented correctly and could be used for analysis and interpretation during the survey.

**Camera equipment**:We used a Nikon D850 camera equipped with a Sigma 50mm ART lens. The camera was set up with Aperture priority with variable ISO and fixed minimum ISO at 100, fixed F-stop 5.6, minimum shutter speed 1/2000 sec AF-F (i.e. AutoFocus – fulltime) as this configuration is best for best for moving objects, with wide-area focus (i.e. not point focus) was used during the survey to capture the data. The camera was securely mounted in a port located on the aircraft's floor. Vertical photo series were manually initiated at the beginning of each transect, and the camera was set to automatically capture images at intervals of 10 seconds using the camera's 'interval' setting. This systematic approach allowed for a consistent and regular collection of photographs throughout the survey.

Prior to the census, a series of step were taken to calibrate the camera and lens to ensure that the to ensure that the captured images provide reliable data. Calibrating a camera for reliable photo-taking during animal counts involved the following steps;

- **Camera Settings:** Camera setting to the appropriate settings recommended (above settings) for the survey. This includes adjusting the exposure, shutter speed, and aperture to ensure clear and properly lit images.
- **Focal Length and Field of View:** Determine the focal length of the lens being used. This information is important for estimating the field of view and the area covered by the camera at different distances.
- **Markers:** Markers on the edge of the runway placed every 20m for 600m meters on both sides from the centre of the airstrip. These allowed to calculate the actual size of objects in the photos.
- **Geotagging:** Enabling the geotagging on the camera to record the exact location of each photo. This aided in accurate spatial analysis and mapping during counts.
- **Actual calibration:** This is the actual calculation of the calibration. We correlated the area on the ground based on counting the markers seen in each photo against the altitude of the photo. The camera was well calibrated if the obtained correlation coefficient is greater than 0.95.
- **Quality Control:** Review the test shots and assess if the animals are clearly visible and identifiable, and ensuring the scale bar is visible and properly aligned.

- **Documentation:** Keep detailed records of the camera settings, altitude, and other parameters used during the survey. This documentation is essential for ensuring the reproducibility of the study.

To facilitate accurate estimation of the area of occupancy and ensure the inclusion of all relevant animals within a transect, several blank images were intentionally captured before and after the outer margins of the wildebeest herd. This aided in delimiting the boundaries of the herd and provided a reference for determining the accurate area covered by the herd. By employing these techniques, the survey aimed to capture representative dataset of the wildebeest population in the study area, while minimising the chances of missing any individuals or underestimating the herd's spatial extent.

We determined where images were taken and their altitude by connecting the photo's time to the GPS track log. By matching the time of a captured image with the corresponding GPS track log entry, we were able to pinpoint where the photo was taken. With location established, we calculated the altitude by subtracting the ground's elevation (from Digital Elevation Models or DEMs) from the GPS device's height in the aircraft. To enrich this data, we integrate Front Seat Observer (FSO) datasheets. These datasheets helped link each photo to a specific transect, providing for its location. Additionally, the observer notes helped to determine the direction of travel (East or West) when the image was captured.

### 2.2.2. Data streams

All images were captured along the transects and carefully saved and organised to ensure efficient data management. Upon landing, the images were immediately transferred and saved to multiple hard drives, ensuring redundancy and safeguarding against data loss. To maintain a systematic record of the images, their names (E://Wildebeest Count Data (SE 52) - 2023/SE_52 Photos/March 29 - 2023 - 1/102ND850/S52_0001.JPG) were assigned in sequential order. This allowed for easy identification and tracking of each image during the data analysis phase. The names of the images were promptly recorded in a spreadsheet, alongside relevant information such as the corresponding transect name and the altitude at which the image was captured.

### 2.2.3. Reconnaissance flights to identify survey area

Reconnaissance flights over two days before (29$^{th}$ and 30$^{h}$ March 2023) the count identified the distribution of the migratory herd and from these flights, the herd distribution was mapped, and a survey area identified. These reconnaissance flights are important in determining the space/time when the wildebeest are formed into large, dispersed grazing herds that are relatively evenly distributed across the short-grass plains. Following this, 13.3 hours of photographic sampling flights were flown along east-west transects covering a straight-line distance of 2332 km. Additionally, two days (one before the actual census and one post census) were used for test and recce flights, and were not included in the actual estimate of the population.

The camera calibration process was done at the airstrip by placing markers 20 meters away from the center of the airstrip. The aircraft then flew over the airstrip at various heights, from 500 to 1000 feet. During each pass, the Rear Seat Observer (RSO) took photos, while the Front Seat Observer (FSO) noted flight details. After landing, photos were downloaded and the markers seen in each photo were counted and correlated with the fawn height to obtain the regression (Fig 2.2).

The camera was securely mounted within the aircraft through a portal in the floor of the fuselage behind the rear passenger seats, ensuring stable and precise image capture to ensure optimal image quality and clarity. The high-resolution aerial photographs obtained through this method facilitated detailed analysis and population estimates contributing to a better understanding of the ecosystem's ecological dynamics.

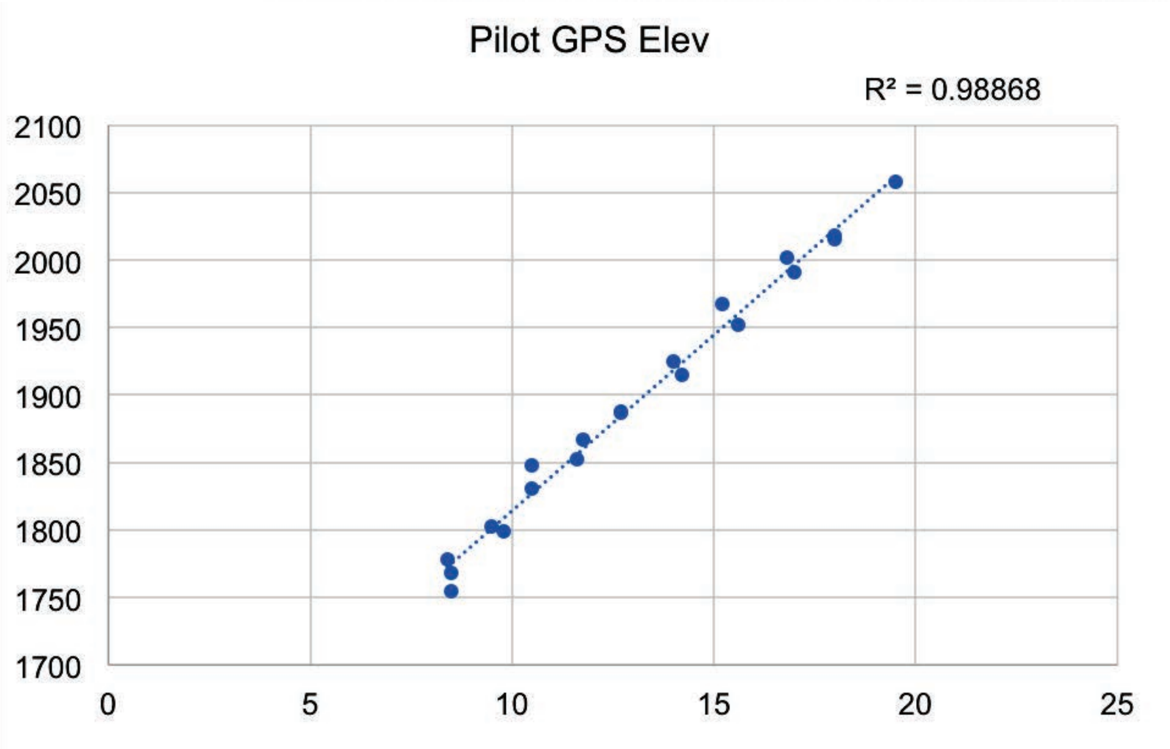


**Figure 2.2**: Calibration parameters

### 2.2.4. Survey flights

During the sample count flight, the aircraft maintained a target altitude of 1000 ft (305 m) above the ground while flying along the designated transects. This altitude was carefully chosen to optimise image resolution while minimising any potential disturbance to the wildebeest caused by the sound of the aircraft engine. By flying at this height, the survey team aimed to capture clear and detailed photographs of the wildebeest population without triggering a reaction that could alter their behaviour. To ensure accurate and consistent data collection, the aircraft's ground speed was closely monitored and maintained as close as possible to 100 knots (185 km/h). However, due to factors, such as strong winds and rising terrain in the East, adjustments were made during the flight. Eastbound transects were flown at speeds ranging from 95 to 100 knots (176 to 185 km/h), while westbound transects were flown at speeds between 110 and 120 knots (201 to 222 km/h).

Specific measures were taken during the westbound transects to accommodate the speed differentials and maintain stability. The aircraft flew at a reduced power setting and utilised 20 to 40 degrees of flaps. These adjustments ensured that the aircraft could maintain the desired speed and manoeuvrability while flying westward. As a result of the speed differentials and adjustments made during the flight, there were slightly varying sample intervals between the eastbound and westbound transects. However, thorough care was taken to maintain consistency and accuracy throughout the data collection process, regardless of the slight variations. Following these flight parameters and adjustments, the survey team aimed to gather precise and reliable data on the wildebeest population, enabling a comprehensive analysis and assessment of their numbers and distribution within the survey zone.

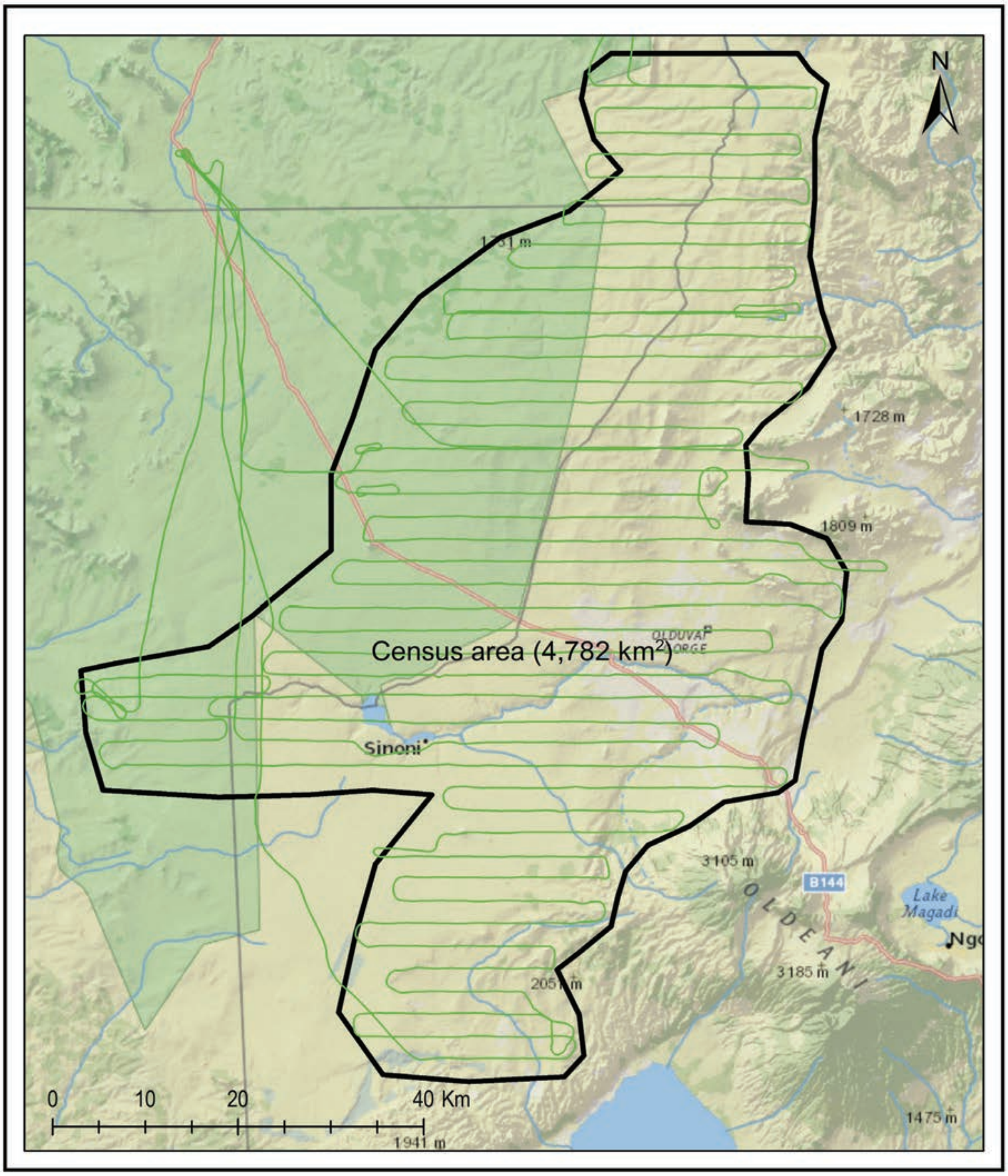


**Figure 2.3**: Transects flown during the 2023 wildebeest count

## 2.3. Data analysis

### 2.3.1. Enumeration of animals in each species

The assessment of the wildebeest population involved a careful process using digital photos displayed on a computer screen. Trained volunteers, under the supervision of staff at the TAWIRI headquarters, systematically, enumerated the number of wildebeests in every photograph. Each photograph was accessed from the summary spreadsheet with clickable links to individual photos and data fields for recording the counts. To ensure precision, each photo was opened using image viewer software (Image J) and zoomed to 50%. The photo was then positioned in the upper left part of the screen, and volunteers systematically scrolled through the images, counting the wildebeest. Each image was counted three (3) times. The team had the flexibility to adjust contrast if needed for better visibility. In cases of large wildebeest herds, Image J's point count tool was utilized to achieve more precise counting. The recorded counts were precisely noted in the spreadsheet.

### 2.3.1. Calculating average density, survey area and total population size

For assessing population numbers from image counts, the approach of Jolly's method II is applied (Jolly 1969). This technique offers population estimate derived by multiplying the average density within each image by the entire survey area. Additionally, a standard error is determined by considering the standard deviation of densities across individual transects. The calculation of image area involves using the lens's field of view and the altitude above ground to determine the extent of each image. Utilizing the wildebeest density observed along each transect, we were able to project this density across the entire area, yielding an estimation of wildebeest density (# of wildebeest / km$^2$). Given the total surveyed area, this density calculation further enables an approximate count of the wildebeest population within that area. Employing cutting-edge statistical methods, such as machine learning (artificial intelligence), holds the potential to yield more precise and resilient wildebeest density estimates. This advancement significantly bolsters the dependability and comprehensibility of the survey findings (Torney *et al.* 2023).

### 2.3.2. Calculation of uncertainty

To address the uncertainty in the estimated density, the Jolly II method with unequal areas, as described by Norton-Griffiths, was employed. This method considered the transect as the primary sampling unit and assumed that the density and area of each transect were known without error. It treats the transects as random samples and adjusted for variations in their areas. However, it is important to note that the Jolly II method does not account for spatial autocorrelation, which is the potential interdependence of observations in close proximity. Recognizing the limitations and the need for more advanced statistical approaches, TAWIRI continues to explore alternative methods that can incorporate spatial autocorrelation (Torney *et al.* 2023).

## 3.0. RESULTS AND DISCUSSION

### 3.1. Photo counts

A total of 4,527 images were captured along 55 transects, 1,883 images of which had wildebeests. The wildebeest herd was categorised into four distinct strata based on location and distribution. The population counts (raw) within the stratum and distribution (Table 3.1 & Fig. 3.1).

**Table 3.1**: Photo counts within the survey area

| Survey area | Counted |
|---|---|
| GSE | 5,308 |
| **Total photo count (Raw)** | **54,134** |

### 3.2. Population estimates

The total number of migratory wildebeests in the Serengeti ecosystem was estimated to be 1,366,109 (+/- 231,741) as summarized in Table 3.2 and illustrated in map Figure 3.1. The results indicate that wildebeest populations were estimated based on the count of raw (counted wildebeests in each photo. The findings show distinct variations in population distribution across these areas. Spatially, wildebeests were well distributed in the Ngorongoro Plains are known for their fertile grazing lands. The same densely distribution was observed in the Serengeti Plains, as these plains are renowned to encompasses savannahs that serve as habitat for wildebeests and other wildlife, making it an ideal location for the wildebeest migration calving season and the plains are traditional routes for migratory wildebeests. The distribution was well observed as well in the Loliondo Plains. The Loliondo Plains is adjacent to the Serengeti and shares some of the same ecological characteristics, making it an essential part of the wildebeest's migratory routes. However, the distribution in this area might be slightly narrower due to factors such as competition with livestock or the availability of resources. Areas around the Ndutu Plains recorded less density, compared to other areas.

Density-wise, the distribution of wildebeests in the GSE exhibits exciting patterns, with varying densities and group sizes across the strata. It is evident that the highest concentration of wildebeests, ranging from 31 to 120 individuals per group, was observed in the Serengeti plains. This area stretches from the northern part of the plains and extends towards the north-western plains of the Ngorongoro Conservation Area. Within the Serengeti plains, the wildebeest population displayed a particularly dense concentration, possibly indicating a thriving ecosystem that supports these animals. The medium density of wildebeests was observed throughout the Serengeti plains. This suggests that while certain areas may have a slightly higher concentration than others, the overall distribution of wildebeests is relatively even across the plains.

**Table 3.2**: Wildebeest population estimates in the Serengeti ecosystem

| Stratum | Estimate | S. E |
|---|---|---|
| GSE | 1,366,109 | 231,741 |
| **Total** | **1,366,109** | **231,741** |

The wildebeest density exhibits a notable concentration in the plains towards the north-western part of the Ngorongoro Conservation Area. This area is an important habitat for the wildebeests, through providing ideal environment for wildebeests to thrive, leading to a higher concentration of individuals in this specific area and serving as a crucial stopover or gathering point contributing to the observed density in the area.

In contrast to the areas with higher densities, the South-east plains of The Ndutu exhibited the lowest density of wildebeests. Here, localised groups of wildebeests are found, suggesting limited food resources, variations in vegetation, or potential predators may influence the lower density observed in this area during the survey.

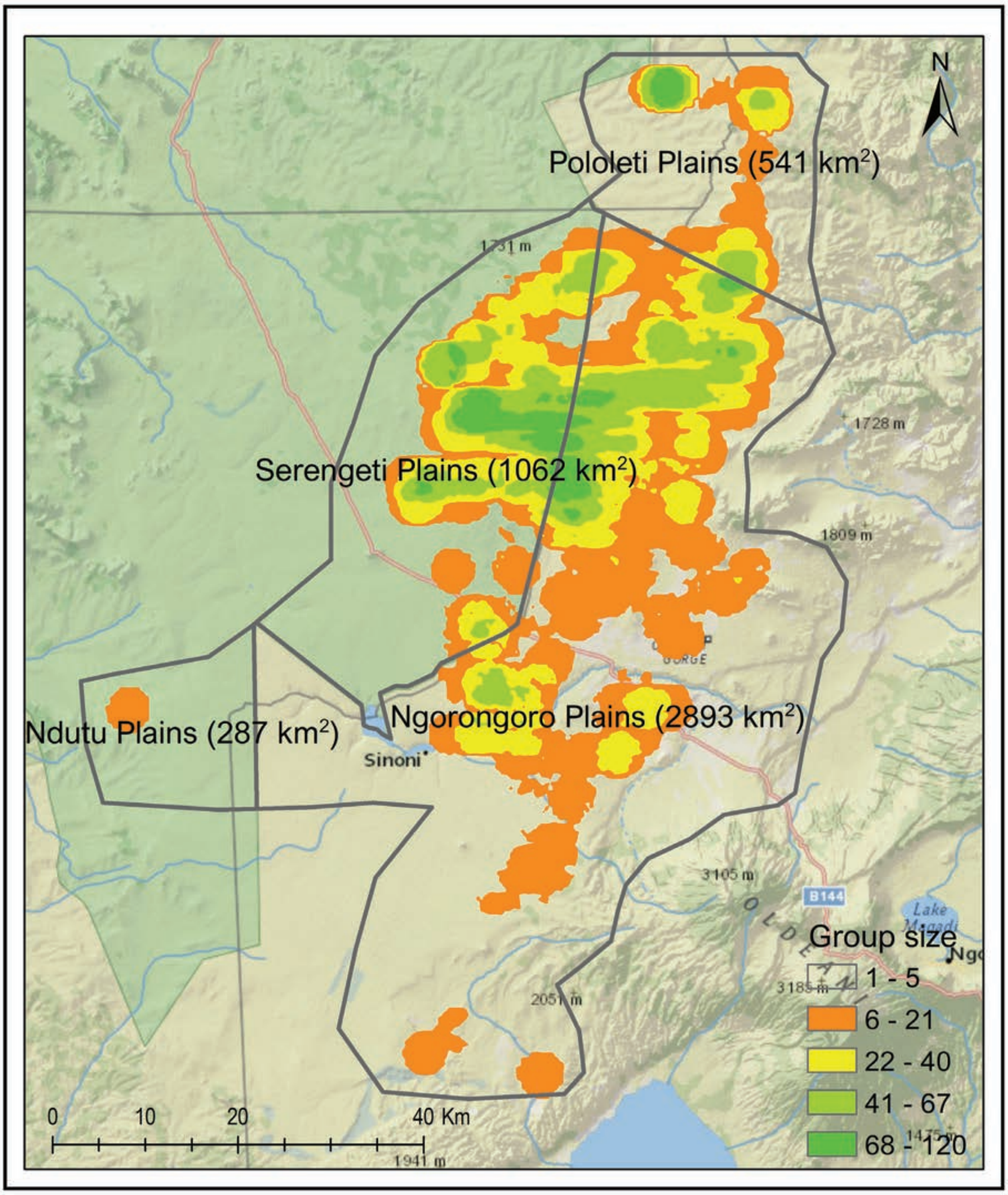


**Figure 3.1**: Distribution and density of wildebeests at the time of the census

## 3.3. Population trends

The wildebeest population trend displayed a notable pattern of growth and fluctuations over the decades, commencing from the 1950s until the early 1970s, during which the numbers were consistently below one million. However, a significant change occurred in the late 1970s when the population surged and exceeded one million, probably due to vaccination of rinderpest in the late 1950's. Subsequently, from the 1990s until 2012, the population has fluctuated around the 1 million mark. However, the 2015 and 2023 counts show a sustained increase in estimated population size to the highest levels yet seen, (Fig. 3.2).

The population of wildebeests in the Serengeti is influenced by various factors, and among them, rainfall that plays essential role. Particularly in the dry season, when resources are scarce, the amount of rainfall directly affects the growth of vegetation, which in turn becomes the primary source of sustenance for the wildebeest population. However, the impact of food availability on wildebeest mortality becomes significant only when population density is considered. During periods of increased rainfall or favourable climate conditions, lush vegetation may be abundant, which supports higher wildebeest reproductive rates and calf survival. Conversely, in drought or unfavourable climatic events, food scarcity can lead to reduced reproduction and increased mortality, resulting in declining population numbers. This underscores the relationship between environmental factors like rainfall, food availability, and population density in shaping the dynamics of the wildebeest population in the ecosystem, a phenomenon further corroborated by existing scientific literature (Mduma *et al.* 1999).

To a less extent, predation could also be a factor influencing wildebeest populations. Predators such as lions, hyenas, and crocodiles target wildebeests during their annual migration and calving seasons (Mduma *et al.* 1999). High predation pressure can cause substantial mortality, leading to a decrease in population numbers. However, there is little evidence that the population is currently being limited by predation as it is currently very high compared to historical counts, and relatively stable. Perhaps more importantly, changes in land use, habitat fragmentation, and human disturbances can disrupt their migratory patterns and access to critical resources, negatively impacting population numbers.

Poaching's impacts on wildebeest in the Serengeti ecosystem are far-reaching, leading to population declines that can disrupt critical ecological dynamics. As a keystone species, wildebeests' decline affects vegetation, trophic cascades, and the annual migration spectacle, altering habitat structure and resource availability for other species. This disturbance waves through the ecosystem, impacting predators, scavengers, and local communities dependent on wildlife tourism, ultimately threatening the balance of the ecosystem.

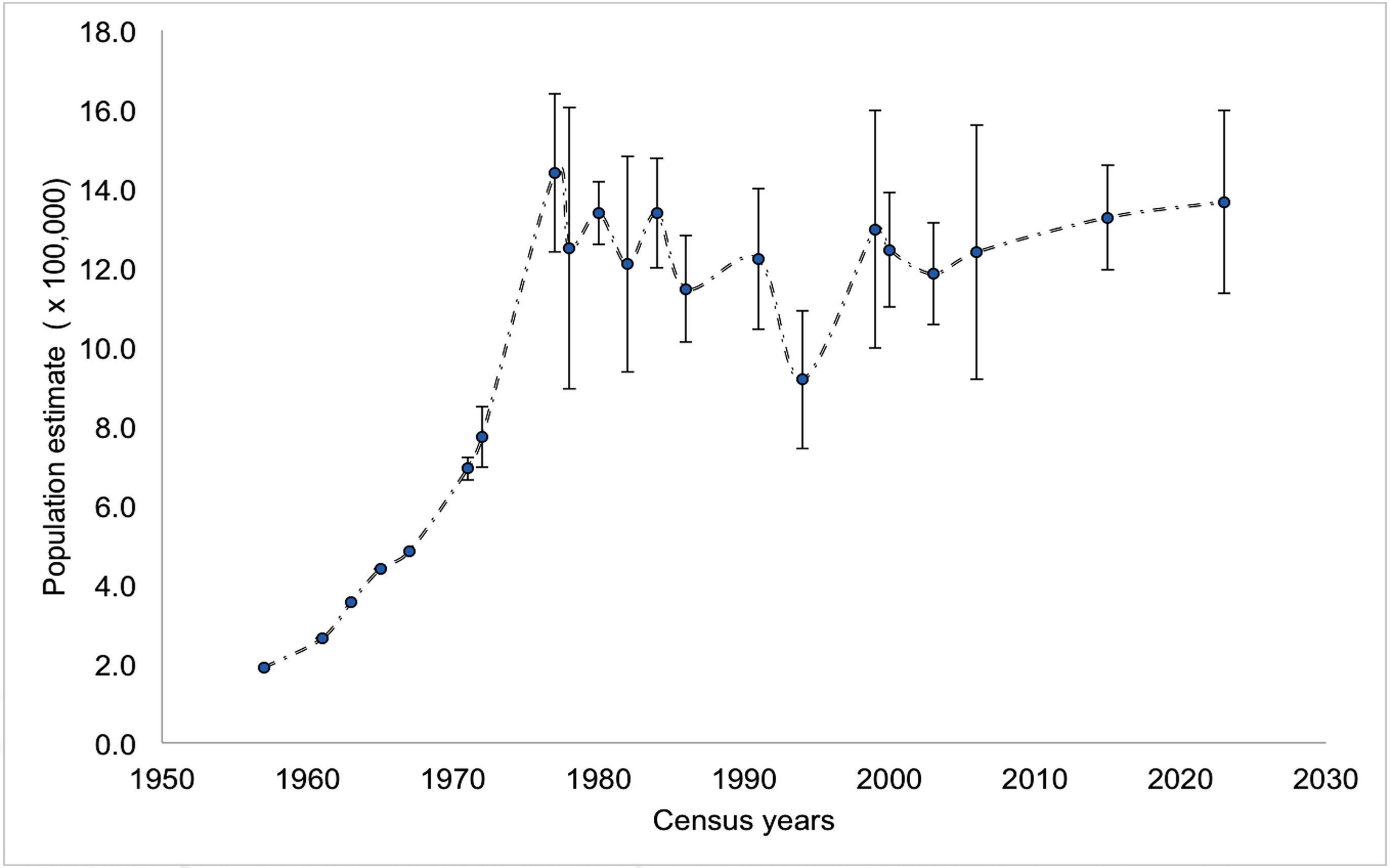


**Figure 3. 2**: Population trend of wildebeests in the Serengeti ecosystem

## 4.0. CONCLUSION AND RECOMMENDATIONS

In conclusion, the survey reveals a noticeable rise in the wildebeest population within the ecosystem, as observed visually and based on population numbers. However, when compared to the findings of the previous survey, there is no statistically significant increase (*d-test=0.91*). It is crucial to acknowledge that the distribution and density of these animals in the plains are dynamic and influenced by various factors, such as habitat suitability, resource availability, and migration patterns. The remarkable concentration of wildebeests in the north-western plains of NCA underscores the ecological significance of this region for the species. To ensure the long-term conservation and sustainable management of wildebeest populations in the ecosystem, the following recommendations are proposed:

- **Continuous Monitoring**: Implement annual monitoring program to track changes in population dynamics, distribution, and habitat preferences of wildebeests;
- **Multifaceted monitoring approaches**: A combination of monitoring methods is recommended to achieve comprehensive data collection. This can include aerial surveys, which provide a broader view of the ecosystem and herds' movements, ground-based observations specifically targeting wildebeest herds, to estimate recruitment, and the application of advanced technologies like remote sensing, Machine learning (AI) and satellite tracking to count animals and track their movements;
- **Employment of imaging technologies**: The integration of advanced technologies, such as remote sensing and satellite tracking, enhances the accuracy and efficiency of monitoring efforts. Real-time and spatially detailed information obtained through these methods offers invaluable insights into wildebeest movements, migration patterns, habitat preferences, and potential threats along their routes. By gathering such comprehensive data, researchers and conservationists can gain a better understanding of wildebeest population dynamics, which, in turn, informs the development of effective and targeted conservation strategies;
- **Habitat Restoration and Protection**: Focus on safeguarding the habitats critical to wildebeest survival, such as grazing areas and water sources (Mara River in particular);
- **Wildlife Corridors**: Maintain corridors between Tanzania and Kenya to facilitate natural migration patterns, allowing wildebeests to access essential resources and promoting genetic diversity;
- **Community Engagement**: Engage local communities in conservation initiatives and raise awareness about the importance of wildebeests in the ecosystem, fostering support for conservation efforts; this will increase their participation in conservation, thus realizing benefits through tourism and conservation projects;
- **Research and Collaboration**: Encourage further research on wildebeest behaviour, ecology, and their interactions with other species, and
- **Artificial intelligence:** Use of machine counts by application of Artificial intelligence (AI)

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