

**ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
DEPARTMENT OF ZOOLOGICAL SCIENCES**



Analyzing the effect of armed conflict, agriculture and fire on the movement and migratory behaviour of White eared kob and Roan antelope in the Boma-Gambella landscape of Ethiopia and South Sudan

A Thesis submitted to the Department of Zoological Sciences in partial fulfillment of the requirements for the Degree of Master of Sciences in Ecological and Systematic Zoology

By

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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

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DEDICATION

I would like to dedicate this thesis to those scouts, wildlife experts, scientists and game wardens who have lost their lives in the struggle to sustain wildlife of Ethiopia and the world at large. I will be pursuing their dreams and vision in the rest of my life so that their sacrifices don't end up in vain.

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LIST OF ACCRONYMS

Acronym	Definition
ACLED	Armed Conflict Location and Event Data Project
AGS	Antelope Specialist Group
APN	African Parks Network
AWT	African Wildlife Tracking
ESRI	Earth Systems Research Institute
EU	European Union
EWCA	Ethiopian Wildlife Conservation Authority
GDP	Gross Domestic Product
GPS	Global Positioning System
HoAREC and N	Horn of Africa Regional Environment Center and Network
IUCN	International Union for the Conservation of Nature
LSCV	Least Squared Cross-Validation
MISE	Mean Integrated Square Errors
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NP	National Park
QGIS	Quantum Geographic Information System
SPLA	South Sudan People's Liberation Army
TFCI	Trans Frontier Conservation Initiative
UCDP	Uppsala Conflict Data Program
UD	Utilization Density (Distribution)
UHF	Ultra-High Frequency
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
WCS	Wildlife Conservation Society

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ABSTRACT

Wildlife migrations are indicators for functionality and connectivity of land or seascapes. A species movement promotes nutrient cycling, seed dispersal, prey predator interaction, as well as species fitness and survival. The disruption of wildlife migration phenomena are alarms to an underlying and complicated socio-political and environmental crisis yet to come. In this thesis I evaluated the disturbance on White eared kob (*Kobus kob leucotis*) and Roan antelope (*Hippotragus equinus*) generated by the armed conflict, livestock encroachment and agricultural investments in the Boma-Gambella landscape. Four years of wildlife telemetry data was collected to analyse and detect the movement and migratory behaviour of White eared kob and Roan antelope against armed conflict, agriculture, fire, livestock and settlements in the landscape. The telemetry data was complemented by the data from five systematic reconnaissance aerial flights. Kernel density estimates, overlay analysis, statistical derivatives and GIS illustration methods were applied to produce results. Migratory kobs have shown behavioural response to the ongoing armed conflict and livestock encroachments by shrinking their former home ranges and making sudden displacements away from conflict hotspot areas. Human footprints and their effect on wildlife conservation in the landscape are evident. The home ranges and movement patterns of resident roan antelopes overlap with the major agricultural concessions and their cropping seasons. The key wildlife core areas, the main migration routes and home ranges exist outside of formal protected areas. The migration route analysis resulted with the longest terrestrial mammal migration and the second largest wildlife migration in the continent.

Key words: White eared kob, Roan antelope, Gambella, Boma, Bandingilo, Agriculture, Conflict, Migration, Home range, GPS collars, Fullata.

1. INTRODUCTION

1.1. Background

Wildlife Migrations are wonders of the conservation world. There are at least three large terrestrial mammalian migrations in the African continent; these are the Zebra (*Equus Quagga burchellii*) migration between Namibia and Botswana, the Wildebeest (*Connochaetes*) migration in the Maasai-Mara of Kenya and Tanzania (Naidoo *et al.*, 2016), and the least known white eared kob (*Kobus kob leucotis*) migration of the Boma-Gambella landscape in South Sudan and Ethiopia (WCS, 2007; Grossmann and Kasahun Abera, 2013; Malik, 2014; Malik *et al.*, 2018). These species seasonally navigate through a landscape that meets their ecological requirements such as breeding, food, water and shelter requirements (Bolen and Robinson, 2003).

Conservation area corridors or protected area networks are important to ensure wildlife conservation and for the continued existence of diverse species and natural communities in the face of both human induced landuse and climate changes (Worboys *et al.*, 2016). These areas should satisfy not only biodiversity surrogates, but also spatial design and socio-political criterion (Margules and Sarkal, 2007). Components of the landscape must be large and connected enough to meet the requirements of species that utilize it, particularly migratory species (Jong *et al.*, 2010; Vasiljević *et al.*, 2015).

Migratory species such as White eared kobs (*Kobus kob leucotis*) have a long perceptual range that enables them to explore greater landscapes and to maintain a steady population status. However, they are seriously challenged and may tend to change migratory behaviours when the landscape is fragmented due to human induced and natural calamities that compromise the connectedness, connectivity and availability of movement corridors (Farina, 2007). Hence, absence of migration is

an indicator for fragmentation and disconnection between two or more landscapes (David *et al.*, 2009). As habitat conditions change in the face of climate change, the range of some species may shift and wildlife must be provided greater opportunities for movement, migration, and changes in abundance and distribution (Edgar *et al.*, 2012).

In this study, I have presented the movement and migratory behaviour of White eared kobs and Roan antelopes. The seasonal abundance and distribution of the migratory and resident species is illustrated in maps. The impacts of armed conflict, agriculture, settlement and livestock on seasonal resource requirements and migratory behaviour of the target species is also evaluated and explained.

The findings of this research could be used as an input for further network of protected areas planning and development of species conservation strategies.

1.2. Literature Review

Wildlife ecologists are nowadays, equipped with technological tools that allow them to obtain data about the dynamics of animal's movements and behaviours (Silke *et al.*, 2011). These datasets are increasing in terms of spatial and temporal resolution and size, together with complex associated information related to environmental context (Urbano, 2015).

Telemetry data has become important input to compute home ranges of wild animal.

A home range is the ecological space an animal must prospect to satisfy its seasonal resource use requirements. The physiological state and the scale of resource requirements determine the extent and ecological complexity of the home range space. Hence, home ranges differ from one species to the other even between resident and migratory members of the same species. Migratory birds followed by aquatic and terrestrial mammals have the largest home ranges.

The concept of home range is more than just the place where an animal seasonally moves. Rather, it is a multi-dimensional space in a landscape or a cognitive map of the species about its environment. The map is updated often with information about the spatio-temporal distribution and abundance of key resource and situations in the landscape. Information about resources those are vital to maintain the fitness of the species in its habitat and so are often updated intuitively. A home range is indeed behavioural response, and not only delineations of species habitat zones (Roger and Michael, 2012).

The behavioural components of movement ecology, like decision-making in navigation and orientation, habitat selection and dispersal are associated with features of landscape ecology (Bolen and Robinson, 2003; Miller and Spoolman, 2015). White eared kobs (*Kobus kob leucotis*) and Tiang (*Damaliscus lunatus*) are among the migratory species of the Boma-Bandingilo-Jongeli-Gambella landscape. They migrate following vegetation greenness, which follows rainfall patterns (Fryxell, 1985; Wild films history, 1983; Malik, 2014).

The conflict in South Sudan and expansion of commercial agriculture has affected wildlife such as the migratory white eared kobs and elephants with other several resident species such as Nile Lechwe (*Kobus megaceros*) and Roan Antelope (*Hippotragus equines*). The war has inflicted damage not only on the socio-economic and political stability, but also on the wildlife species by paving the fertile ground for poaching and wildlife trafficking, as it interrupts their migration routes and patterns. Migratory species such as White eared kob, Tiang and Elephant pay the highest price. This will in turn compromise the fitness and survival of these species with a danger of knocking the population dynamics (Edelhoff *et al.*, 2016). Any deviation in the pattern of movement including delays in arrival dates to breeding grounds in Gambella National Park despite favourable environmental conditions could be attributed to the influence of the conflict in South Sudan.

This later in turn will have a heavy consequence on the survival of the species involved and the landscape in general. The Boma-Gambella landscape represents one of the most bio-culturally diverse areas in Africa. The ecological unit forms a transition zone between the Guinea – Congolian and Somali – Maasai biomes with patches of Afro-montane forests (David and Michael, 2013). This unique, fragile and little-known wilderness area exhibits the second largest terrestrial mammal migration in the world; i.e., the White eared kob migration, which is comparable to the wildebeest migration of the Maasai - Mara ecosystem between Tanzania and Kenya (WCS, 2007). The total population of white eared kobs in the Boma-Gambella landscape is estimated to be around a million. Out of this number, close to 50,000 are estimated to be resident in Gambella region (Gambella National Park and its surroundings). A considerable population (est. 400,000) is known to forage for resources seasonally between Boma-Bandingilo in South Sudan and the Gambella landscape in Ethiopia. The remaining population is estimated to be resident in the South Sudan part of the landscape.

As a result, there is a wide difference in the abundance and distribution of this species in both landscapes between the dry and wet seasons (Fryxell, 1985, Fryxell and Sinclair, 1988; WCS, 2007; Grossmann and Kasahun Abera, 2013).

Roan antelope (*Hippotragus equinus*) is among the endemic antelopes of the African continent. Roans are the second largest antelopes in Africa, next to Eland (*Tragelaphus oryx*). Once known to be widely distributed in the tropical and subtropical grasslands, savannas, and shrub land biomes of the continent, at present most of the populations are found in isolated groups spreading in its range (Alpers *et al.*, 2004; Carl *et al.*, 2016).

Even though, it is rated as least concern by IUCN red list of threatened species (IUCN ASG, 2017); it is losing its core habitats due to agriculture, settlements and infrastructure developments, as well as, they are highly hunted for bush meat, and collected for live trade in Africa. As a result, it has been reported now as locally extinct from Burundi, Eritrea and possibly from Gambia (IUCN ASG, 2017). It has been reintroduced to Swaziland, and very decimating trends are presented from Kenya (Charles *et al.*, 2012; Kimanzi and Wanyingi, 2014).

The riverine systems in the Boma – Gambella landscape have contributed to the formation of vast wetlands, e.g. the Sudd, Machar, and Lower Gilo and Duma wetlands. The landscape supports a phenomenal diversity and abundance of wildlife, and sustains a large population of white-eared kob, African Elephant, the endangered Nile Lechwe (*Kobus megaceroes*), Roan antelope Tiang (*Damaliscus lunatus*) with numerous fish and endangered bird species (Grossmann and Kasahun Abera, 2013). Even though, these are geopolitically found in two sovereign nations - Ethiopia and South Sudan; apart from the wildlife, the landscape entertains numerous other cross border traits, such as rivers and transhumance.

Transhumance leads to demographic changes and apparent conflicts in the landscape (Dereje Feyisa, 2009; 2010). The competing and conflicting landuse, cattle raids, lack of socio-economic infrastructure, uncertain biodiversity and wildlife status, lack of appreciation to biodiversity and wildlife values and lack of integration among stakeholders are among the many challenges facing the overall development of the landscape (Michael and Catherine, 2001; Angela, 2017). The fertile soils, abundant rainfall and irrigation potential have attracted agricultural-based investments in the region. Since 2008, large scale land concessions for agriculture have been issued to foreign investors with many small-holder concessions leased to national investors in the Ethiopian part of

the landscape. This is mostly done at the expense of its unique ecology and rich biodiversity resources (Desalegn Rahmato, 2011). Investors are engaged in different activities including mechanized rice farming, which demands plenty of water.

The investors extract water from rivers that charge the wetlands. In most cases, agricultural investment lands are not accurately mapped, consequentially, some of them even overlap with fragile ecosystems such as wetlands and existing protected area systems (Rose *et al.*, 2009; Stebek, 2011; Alemu Getnet, 2012). Habitats of all types, including grasslands, wetlands and river systems, continue to be fragmented and degraded at an increasing rate. The destruction and degradation of such natural habitats represent the single most important driver of biodiversity loss (Thomas *et al.*, 2002).

The landscape has gone through decades' long civil war, and currently is one of the conflict hot spots in the Horn of Africa. Since the recent outbreak of conflict in South Sudan in December 2013, a total of 50,000 people has been killed with an estimated 4 million people displaced. Armed Conflict Location and Event Data Project (ACLED) report published at the end of December 2017 estimates a total of over 4000 conflict events since 1st of December 2013.

The economy of South Sudan is suffering at an annual drop of 15% of the national GDP. It is also costing the neighbouring countries a fortune. During the last five years since 2013, the total cost of the conflict in South Sudan to the national economy, the economy of its immediate neighbors (Ethiopia, Kenya, Sudan, Tanzania and Uganda) and to the international community is estimated to be 28, 53 and 30 billion USD; respectively (Davis, 2015). The connectivity of the Boma-Bandingilo and Gambella landscapes is evident from the fact that, up until 31 January 2018, Gambella region hosted 408,408 (95.2%) out of the 428,928 refugees from South Sudan, mainly Nuer communities (UNOCHA, 2018). The conflict has also caused similar loss on wildlife, such as elephants and

white eared kob both migratory large mammal species of the landscape (The Guardian, 2014; David, 2015; Keith, 2016)

Since the outbreak of the insurgency in 2013, around 5000 government soldiers and 3000 rebels have been deployed inside Boma National Park (David, 2015). Several Wildlife Rangers and Managers including the warden have sacrificed their lives (WCS, 2017). The Park infrastructures are destroyed and have very few or no chance of maintaining their Park management system (Sudan Tribune, 2014). As a result, the presence of Park Rangers in their field missions is inconceivable, which creates opportunities for poachers, wildlife traffickers, bush meat users and traders. Wildlife is left alone and stranded between fighting factions and on the line of fire, becoming intentional and collateral casualties of war (Christina, 2014, Kaitlyn *et al.*, 2016). Besides, poachers and wildlife traffickers, there are three factions fighting in the Boma-Bandingilo-Gambella landscape. These are the government forces (SPLA), the SPLA defectors led by opposition from Lou Nuer and the Murlle led by David Yau Yau. The opposition factions (Lou Nuer and Murlle) also fight between each other with a long history of hostility due to cattle raiding. The Murlle tribes are also the worst night-mares for the Anyuak tribes that live both in the Jongeli state of South Sudan and Gambella region of Ethiopia (The Daily Mail, 2014). In addition to environmental and physiological cues, conflict also drives wildlife to migrate to neighbouring safe grounds; i.e, Gambella National Park. Unfortunately, these perceived safe grounds are not safe enough to safeguard the resident and migratory species of the landscape, as they are already altered by commercial agricultural practices. As a result, the wildlife in this landscape could be considered as the most disturbed wildlife population in the continent. As already mentioned, the conflict in the landscape has disrupted the functionality of protected areas management. To make matters worse, the designation, design and setting of the protected areas themselves seem hardly realistic to safeguard the biodiversity in the

landscape. More than half of the wildlife core areas and migration routes are outside the formal protected area system of the landscape.

The progress on the innovations of telemetry techniques has enabled wildlife ecologists to understand a wide array of wildlife related issues (Urbano, 2015). Provided that careful handling and interpretational approaches are used, behavioural and evolutionary ecology dimensions of wildlife such as resource use, home ranges, dispersal, and population dynamics, and response to conflicts, climate change and other anthropogenic stochastic could be derived from tracking data (Weerd *et al.*, 2015; Torres *et al.*, 2017). The availability of large quantity of tracking data on multiple species across large swath of landscape requires the help of appropriate statistical and spatial models. If the goal of an analysis is to infer the behavioural states of an animal, then observations need to be made at a temporal scale that is meaningful regarding the behavioural dynamics of the animal (Long *et al.*, 2017).

The first puzzle to deal with, while investigating movement ecology of migratory animals is to know what drives the orientation and timing of their migration. The decisions to migrate – when, how, and where, are governed by both internal (physiologic) requirements and external (environmental) conditions. It requires tuning once behaviour to changing internal requirements as per the development of environmental states (Silke *et al.*, 2011). These feedbacks are called cues, which are unique among the different migratory taxa, i.e. fish, insects, reptiles, birds and mammals.

Migratory taxa, particularly birds, are not distracted by the false glitters of their respective environments, i.e. genuine environmental stimuli are filtered by the hypothalamic-pituitary-gonad axis, to initiate a response – the migration. Even though some movement ecologists conclude that, some animals use magnetic fields, the sun, and the relative pattern of skylight polarization and stars for orientation and landmarks and odours for navigation cues are considered (Marilyn *et al.*, 2012).

However, the puzzle remains unsolved yet for many animals on how they orient and navigate during their migration (Winkler *et al.*, 2014). Besides, internal physiological and development circumstances (e.g. change in hormone levels) and an endogenous circadian rhythm (biological clock), the photoperiod stimulated “Zugunruhe” – the anxiety to move or migratory restlessness; coupled with prevailing weather conditions (e.g. temperature, wind, drought, precipitation or water discharge in rivers) are accountable to set the timing for migration (Heerah *et al.*, 2017).

The spatio-temporal overlaps between the major environmental cues in the landscape such as vegetation status, temperature, precipitation, breeding behaviour, against the actual status-quo of movement and migration patterns were analysed and compared to determine the environmental cues that play the primary roles in the species migration phenomenon of the landscape. Already few studies have tried to associate the timing of White eard kobs (*Kobus kob leucotis*), and Elephant (*Loxodonta africana*) that seasonally migrate in the Boma-Bandingilo-Gambella landscape with palatable vegetation greenness, which follows rainfall patterns (Malik, 2014).

The concept of home range is more than just the place where an animal seasonally moves. Rather, it is a multi - dimensional space in a landscape or a cognitive map of the species about its environment. This map should be updated often with information about the spatio-temporal distribution and abundance of key resource and situations in the landscape. Information about resources those are vital to maintain the fitness of the species in its habitat and so are often updated intuitively. A home range is indeed behavioural response, and not only delineations of species habitat zones (Roger and Michael, 2012). Armed conflict and agriculture could fragment habitats and alter home ranges (Malik *et al.*, 2018 and David *et al.*, 2009). The Boma-Gambella landscape have been affected by armed conflict and agricultural investments. It is not known much how wildlife have responded to these threats.

1.3. Research Objectives

1.3.1. General Objective

- To investigate the impacts of armed conflict, agricultural investments, fire, livestock and settlements on the movement pattern and migratory behaviour of White eared kob and Roan antelope in the Boma-Gambella landscape.

1.3.2. Specific Objectives

- To map the seasonal population abundance and distribution trends; movement patterns and routes, home ranges against the extent of existing Protected Areas in the landscape focusing on White eared kob and Roan antelope
- To detect the impact of armed conflict, livestock encroachments and agricultural investments on the biodiversity of the Boma-Gambella landscape,
- To detect behavioural responses of White eared kob and Roan antelope to the threats mentioned above.
- To make recommendations on the potential transboundary conservation area networks between Ethiopia and the Republic of South Sudan.

2. THE STUDY AREA, MATERIALS AND METHODS

2.1. Description of the Study Area: The Boma-Gambella Landscape

The Boma-Gambella landscape is a transboundary landscape between Ethiopia and the Republic of South Sudan, which stretches from Gambella region in South-western Ethiopia to the Boma - Bandingilo landscape of the Jongeli and the Eastern Equatorial States in the Republic of South Sudan. It encompasses the Boma and Bandingilo National Parks of South Sudan and the Gambella National Park of Ethiopia. There is great potential for the establishment of cross-border protected area networks covering large extent of wetlands, lush savannah, lowland and riverine forests.

An important feature of the landscape is its hydrology, manifested largely by the expansive networks of both seasonal and permanent wetland. Pibor, Akobo, Gilo, Alwero, and Baro rivers form the Sobat river system, contributes up to 40% of the water of the White Nile at Malakal and 15% at Lake Nasir (Jonker *et al.*, 2015). Within 100 km west of the Boma-Gambella landscape is one of the world's largest, unique and valuable freshwater ecosystems – the Sudd Wetlands, which was formed and sustained by the flow of White Nile. The Sudd wetlands and the Jongeli plains form Africa's largest intact Savanah (57,000 km²), that is three times larger than the Serengeti National Park (John and Hannes, 2016; Angela, 2017).

Boma-Gambella is part of the White Nile river basin system with mega diversity ecosystem that supports the only wild population of Nile Lechwe in the world, a viable population of Shoebill Stork (*Balaeniceps rex*); one of the world's largest wildlife migration phenomena – the migration of White eared kobs - that move in hundreds of thousands seasonally between Ethiopia and South

Sudan in search of resources and breeding grounds as well as thousands of Zebras, Mongolian Gazelles and Tiang (WCS, 2007; Grossmann and Kasahun Abera, 2013; Malik, 2014; Malik *et al.*, 2018). For this study, the geographic scope is restricted to the Boma-Bandingilo and Gambella landscapes using 95% Kernel home range of the migratory white eared kobs as a reference. Geographically, the 95% Kernel density home range of the white eared kob (est.73891 km²) extends from 350000 to 700000 UTM Easting and from 520000 to 1010000 UTM Northing (Fig. 1).

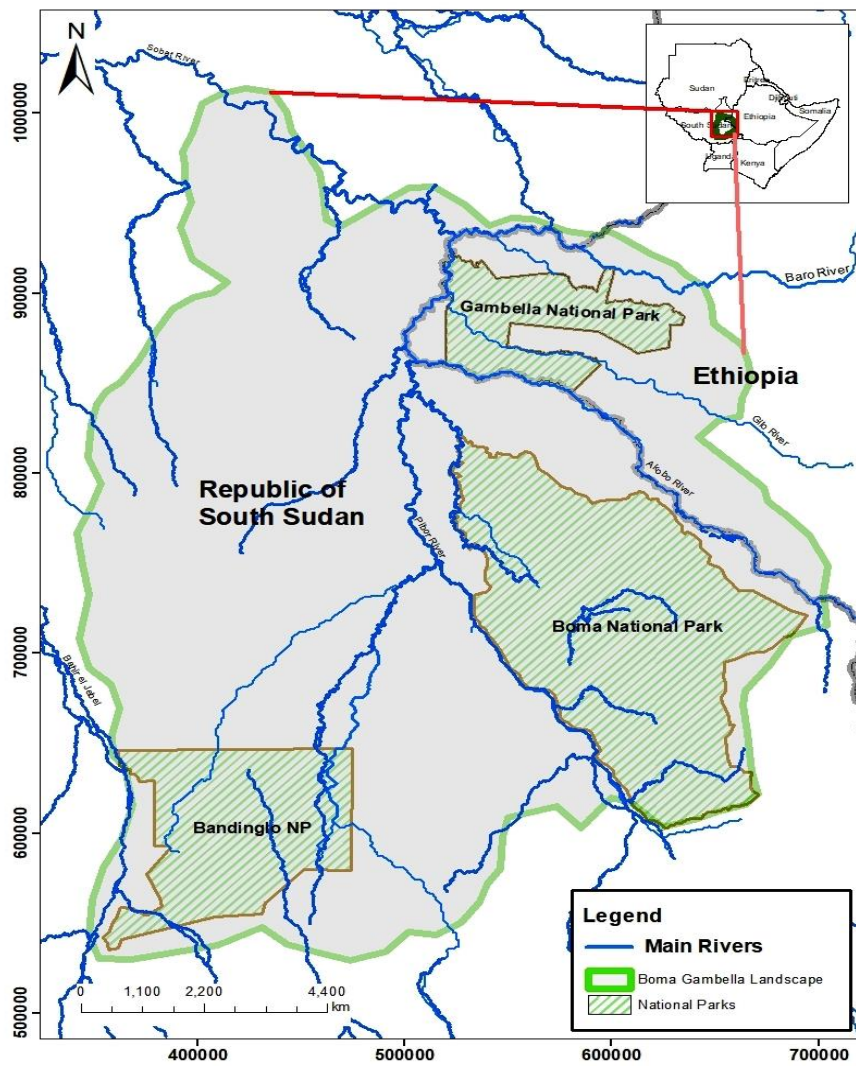


Figure 1 Location of Boma-Gambella landscape

2.2.Materials

2.2.1. Aerial surveys

The equipment's and aircrafts used for the aerial survey were used as per the recommendations in Norton-Griffiths (1978) and Frederick *et al.*, (2010). A total of five aerial surveys missions were undertaken in dry season 2009, 2010, and 2015, with two (wet and dry) season survey missions in 2013. Cessna 182; Cessna 206 and high-winged Cessna Caravan 208 aircraft fitted with flight GPS (Garmin GPS map 296 and 396) were used to undertake the aerial surveys. A lesser radar altimeter was used to monitor and control the flight altitude (106.7 m above the ground), so that the strip width is maintained near to 150 m on both sides of the transect flown. A Nikon D90 camera and a Sony high definition audio recorder were used to take pictures and to record observations during the surveys. Prior to each flight mission the camera and audio recorder were synchronized with the time stamp of the flight GPS. The Flight GPS was set to take automatic track point record at every 3 second time interval. That means, at 180 km/hr. flight speeds, the flight GPS takes one track point after every 150 m transect length flown. In this way, any pictures or observation made has a locational attribute collected by the GPS. The audio recorder was connected by a cable to the main intercom system of the aircraft, so that every communication during the flight was recorded.

2.2.2. GPS collars

All 70 GPS collars were supplied by the African Wildlife Tracking (AWT) company based in South Africa. The AWT approach combines GPS/Satellite/UHF tracking systems that use satellite technology to relay real time and historical animal data. The satellite tracking unit is based on a mobile global two-way communication platform utilizing two-way data satellite communication complete with GPS systems.

2.2.3. Data transcription and handling

The audio to text transcription was exhaustively made with the support of Audacity (a free multi-track audio recording and editing software) on to a microsoft excel table. Then transcribed observation data was geo-tagged with the help of GpsEventSync software, capable of synchronizing the timestamps on the audio recorder and the camera with the timestamp of the GPS device. The data were handled in an excel database before converting to ESRI Shapefiles using QGIS add delimited text layer tool.

2.2.4. Data analysis and interpretations

QGIS 2.2.0, R 3.3.2 and RStudio 1.0.136 with different plug-ins and packages were used to clean, analyze and interpret the data.

2.3. Data Collection Methods

2.3.1. Abundance and distribution data

The Systematic Reconnaissance Flights (SRF) survey methods as explained by Norton-Griffiths (1978) and Frederick *et al.*, (2010) were strictly followed. One wet season (May – October) and four dry season (November – April) surveys were undertaken. First the survey zone was decided and stratified. The general habitats of White Eared Kobs (grasslands and open woodlands) were the focus of the survey zone stratification. Gambella National Park and 5km buffer zone around the boundary of the park was delineated as a core areas survey block. The grassland and open woodland areas in the lower Akobo river areas were delineated as the South survey block. The delineation was done on QGIS and the layer was saved as a shapefile.

Using the survey blocks boundary as a constraining feature and with a spacing of 5 km, regular points were generated using the regular point tool in QGIS. The sizes of the core area and south survey blocks were calculated to be 10290 and 6079 km²; respectively.

The main ecological units, such as river basins and wetlands have an east-west alignment. To avoid the bias of these ecological units on wildlife observations, the flight routes were laid having a north-south alignment. The regular points adjacent or nearby to the southern and northern edges of the survey blocks were selected and saved as separate shapefile and later used as a transect start and end points. Then the starting and ending points were connected to form a flight route considering the time of survey (morning or afternoon) and the endurance hours of the aircraft used in every flight mission. The daily flight routes were uploaded onto a flight GPS (Garmin GPS Map 396).

The flight GPS was used to record flight tracks – later called flight efforts besides helping as a navigation device. A total of 57 transects (35 in the core survey block and 22 in south block) were flown. All transects were less than 45 minutes of flight time in length. The total transect length flown, excluding the U-turns at the starting and end of transect points was 3274 km (i.e., survey area over spacing of transects). The survey pilots in charge have 200 hours of minimum flight hours logged and at least 20 hours of survey flying at low level, with a proven ability to maintain a target flight height of 350 feet (106.7 m) above ground level and kept ground speed at or near 180 km/hr.

A front seat observer (FSO) with knowledge of using GPS and map reading was assigned to measure flight height using radar altimeter, to help the pilot in navigation, as well as taking photographs and calling of transect starting and end points to the other crew members throughout the survey missions. The FSO does also all the uploading of flight routes on to the flight GPS and

downloading of all flight GPS tracks, audio recordings, photographs, height measurements in to a structured database. I was the FSO and data manager in most of the survey missions.

Two rear seat observers (left and right RSO) with good knowledge of identifying species from distance were assigned and calibrated to make calls of species or human activity observations as they appear in to their respective strip widths. The RSOs went through refresher training in animal identification, focusing on species of the landscape and tested by ecologist for their viewing accuracy using a snapshot view of animal picture on slideshows.

During ground calibration, the air craft was positioned on a level ground in a 'flight altitude', with the nose pointing low until the upper door frame is perfectly horizontal. A flat leveled ground on both sides of the aircraft was maintained. Each RSO was asked to take a comfortable position in his/her respective seat. Then, as illustrated in figure 2, the RSO was asked to look out and inform when the bottom edge of the side window (a'), the streamer rode (a) and the right edge of the rear tire of the aircraft are exactly aligned. Once that is maintained, the lower streamer rod was affixed on to the struts carefully using strong duct tape. The alignment is frequently monitored by the RSO while the rest of the survey crew fixes the rods. Then, a line was marked on the ground (A) with a thin line of duct tape parallel to the lower streamer and lower edge of the viewing window. Only 6% of the survey blocks were sampled during the surveys.

The observations were limited to a strip width of 300 m (i.e., 150 m on both sides of the transect line). Hence the RSOs were pre-calibrated to have a strip width of 150 m on each side. Throughout the survey the pilot with the help of radar altimeter operated by the FSO was maintaining a flight height of 350 feet (106.7 m) at a flight speed of 180 km/hr.

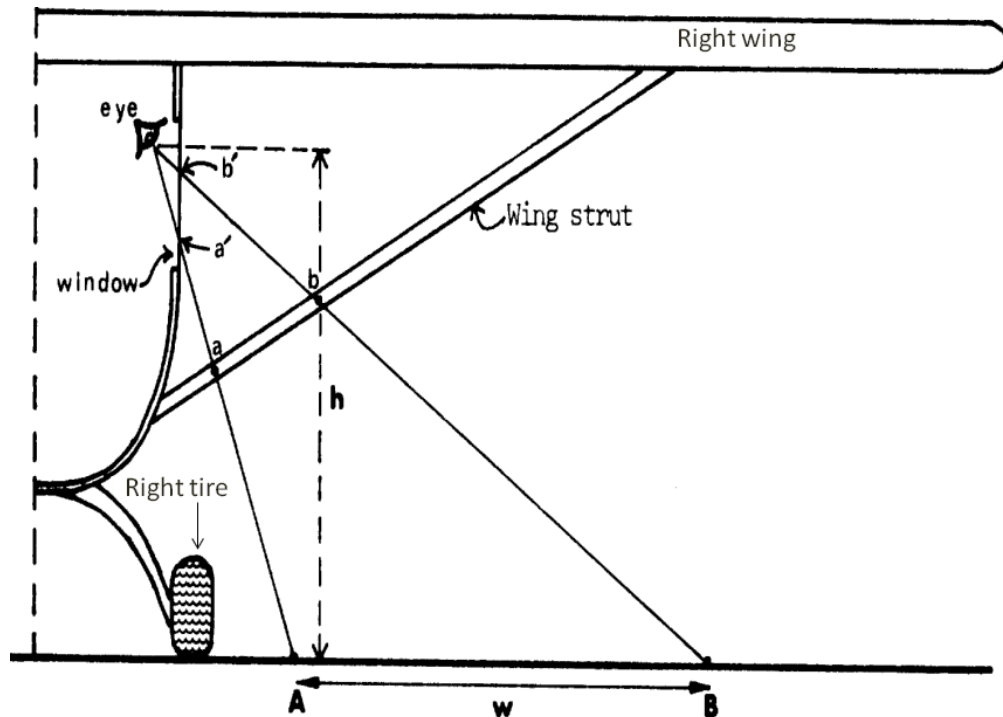


Figure 2 Measurements needed while calibrating rear seat observers before undertaking systematic aerial surveys (adopted from Norton-Griffith, 1978)

Having this in mind, the exact eye height (h) of the RSO while seated on pre-established comfortable position was measured perpendicular to the first straight line (A) marked on the ground. The ratio between the target flying height (106.7 m) and the target strip width (150 m); i.e., $106.7 \div 150 = 1.406$ is used as a constant multiplier to the eye height (h) of the RSO; the result of which is the distance between the first and the second (B) straight lines on the ground. This ground distance is the exact scale representation of 150 m strip width at 106.7 m flying height. Once the position of the second straight line (B) is fixed on the ground, the top streamer rod is fixed on to the wing strut (b) by aligning the line on the ground and the streamer rod. The position of the third alignment line (b') is marked with a thin line of duct tape on the viewing window parallel to the RSO eye height. The process is reiterated for the left RSO as well. The only difference is on the ground distance which is determined by the eye height measurement of the left RSO.

Test flight was done to check the animal spotting accuracy of the observers at increasing flight heights and strip width. This was done by putting 50 markers on both RSO sides spaced at every 20m over one km distance. A two-marker space gap was made between the 25th and 26th markers. The central position point of the gap space was marked and saved on the flight GPS. This point was assumed as a point through which a transect line passes perpendicular to the alignment of the markers. A test flight was flown passing through the central point at 106.7 m above the ground and more. The RSOs record the number of markers observed, while the pilot operates the aircraft to fly at 180 km/hr. and at different flight heights determined by the FSO with the help of radar altimeter. This process was repeated 15 times. After the test flight, the recording of radar altimeter (RA), Right-RSO and Left-RSO observations were encoded on to an excel spreadsheet. The data was plotted as XY chart with the bottom (X) axis of the chart showing RA and the left (Y) axis showing R-RSO or L-RSO observation data. A linear trend line was added on the graph. The equation and R squared of the trend line were displayed on the chart.

The equation gives, strip width (y) = flight height multiplied by the slope of the trend line plus the intercept. The R square value indicates how accurate the observer was at a certain flight height. Proper calibration of observers gives R square value greater than 0.85. This assures that, at 106.7 m flight height each RSO can make observations with in 150m strip width in both left and right sides of the transects. This gives an overall survey sampling size of 6% (Fig.3).

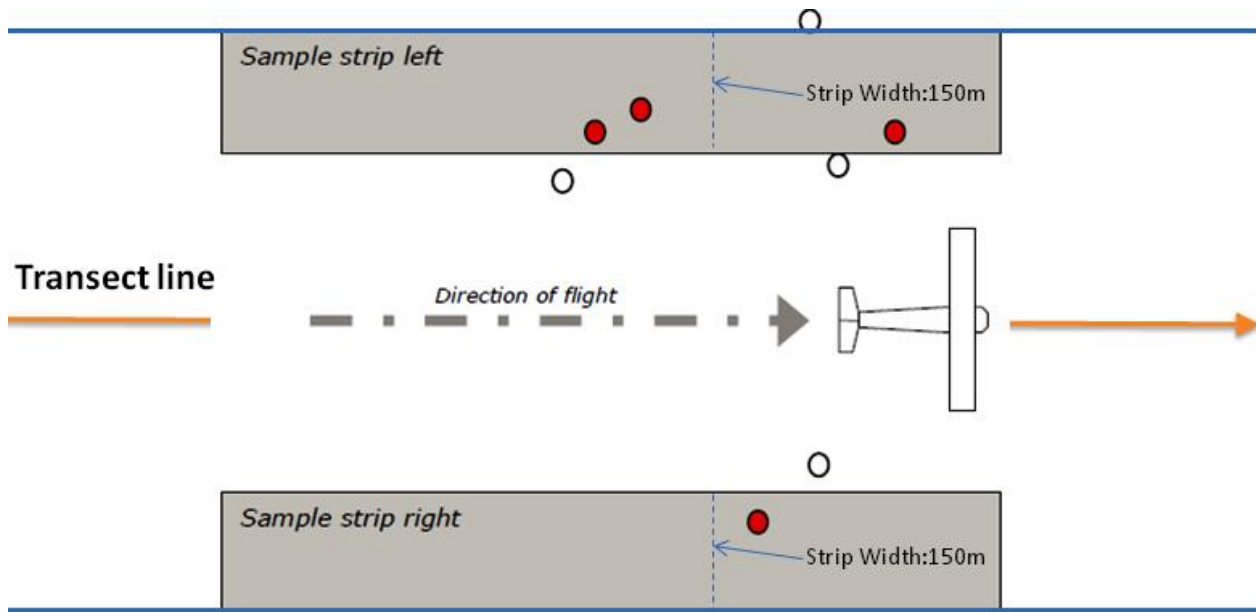


Figure 3 Dual counting of sample striped during aerial systematic reconnaissance flights (adopted from Frederick *et al.*, 2010).

The camera and audio recorders were perfectly synchronized with the time stamp of the flight GPS with a second to second accuracy level. The audio recorder was connected to the intercom system of the aircraft. So that, every conversation during flight was recorded. For this reason, the crew members were communicating only issues concerning the flight and the observations. After every flight, the audio records, the picture taken by the FSO, the GPS tracks automatically recorded by the flight GPS were all carefully download by the FSO and stored in a survey database.

The audio records were then listened on audacity audio editing software to transcribe the observation records and counts, the caller (Left or Right RSO), the time of calling, the transect number, the date of the survey and the flight height in to an excel spread sheets.

Then, the transcribed data was synchronized and geo-tagged with the track record of the flight GPS using a GpsEventSync software. This process makes all the observation to have a locational (spatial) component. Five aerial surveys were undertaken in 2010, 2013 (twice) and 2015, and data was managed in such a way to map the seasonal abundance and distribution of wildlife in the Gambella landscape.

2.3.2. Tracking animals' movement using GPS collars

The GPS collars were bought from Africa Wildlife Tracing (AWT) Company based in South Africa. A total of seventy satellite GPS collars were mounted on White eared kobs (64) and Roan (6). Satellite GPS collars were chosen over VHF and GSM devices, because the first once are based on a GPS/Satellite/UHF tracking system that uses satellite technology to relay real time and historical animal data. The satellite tracking unit is based on a global two-way communication satellite platform. This gives an opportunity to access and re-programme the collars remotely. The animal was first immobilized with an antidote injection shot from a darting gun and administered by a veteran wildlife veterinarian. Both ground and aerial based darting methods were used. The first mission partly used wide nets to trap and dart the animals; whereas, the second mission was done by approaching and darting the animal by a helicopter (Plate.1). The first collaring mission fitted 43 collars on kob in 2013. The cost of purchasing 18 collars and the ground collaring operation was covered by EWCA, whereas the cost for the remaining 18 collars and aerial collaring operation was covered by HoAREC&N with a fund from the Embassy of Kingdom of the Netherlands (EKN). All the cost for the purchase of collar and collaring operation during the second (2015) collaring mission was covered by HoAREC&N with a fund from the European Union through the Intergovernmental Authority on Development (IGAD).



Plate 1 Collaring team fitting a GPS collar on Adult Male White eared kob after the animal was darter with antidote from a helicopter.

Each collar was programmed to send 6 locational GPS fixes every day. The collar sends the GPS fixes to a geostationary satellite which has a ground control station and a server in South Africa at the Africa Wildlife Tracking Company headquarters. The wildlife collaring was done in 2013 and 2015. The tracking was done from 2013 to 2015 and from 2015 to 2017 for the collars installed in 2013 and 2015, respectively. The movement data was continuously monitored and downloaded monthly using a secure login detail granted by the collar manufacturer and supplier (AWT). The data that was received as comma delimited text (csv) file was saved as a separate raw data. Cleaning, aggregation and conversion to shapefile was done on a copy of the raw data.

2.3.3. Data on environmental cues and disturbance agents

The normalized difference vegetation index (NDVI) data was downloaded from Geo-Wiki's engaging citizens in environmental monitoring portal. Health plants (chlorophyll) strongly reflect

and absorb near-infrared (NIR) and red light (Red) bands of the electromagnetic spectrum, respectively. NDVI quantifies vegetation by measuring the difference between near-infrared and red light. NDVI always ranges from -1 to +1. -1 denotes no (dry) vegetation or water bodies and 1 indicates highly green vegetation state. But when NDVI is close to zero, there isn't a green leaf and it could even be an urbanized area.

NDVI is calculated as:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Fire ecology data was downloaded from The National Aeronautics and Space Administration (NASA's) moderate resolution imaging spectroradiometer (MODIS) programme portal. The datasets for the conflict hotspot analysis were downloaded from two sources, the Uppsala conflict data program (UCDP) and armed conflict location and event data (ACLED) project portals.

The western limits of the already developed agricultural concessions were traced from online google earth and bing maps. The layer was validated by real-time land cover map on global forest watch portal. The cropping pattern data was downloaded from the United Nations Food and Agricultural Organization (FAO) website.

2.4. Data Processing and Interpretation Methods

2.4.1. Trends in population abundance and distribution

The population estimates were computed based on Norton-Griffiths (1978) and Frederick *et al.*, (2010). The aerial survey results were aggregated and compared seasonally and between survey blocks in order to detect the changes in the abundance and distribution of the target species. The total length of transects (**TL**) flown multiplied by the strip width (**Yi**) gives the total survey area covered (**Z**). The sum of observation counts (**Zi**) from all the groups (**n**) encountered per species gives the sample population size. The population density (\hat{R}) was computed by dividing the sum of **Yi** by **Zi**. Finally, the total population estimates (\hat{Y}) for each survey block was calculated by multiplying the size of the survey block (**Z**) by the population density (\hat{R}). The observation counts were harmonized with a quarter degree grid cell across all transects lines flown and displayed on a map with categorical legends to show seasonal distribution of the species.

2.4.2. Movement pattern and home ranges

The migration routes were generated from the telemetry data using point-to path plug in QGIS. The GPS fixes across the tracking period (2013 – 2017) were aggregated per species after they were given a sequential order based on dates. This chronological order number, which represents temporal aspects of each GPS fix, was used as a reference to group and connect the sequential points into a line or path. The orientation of movement, trajectories and distances travelled and unusual displacements were extracted or interpolated using path segmentation based on Fuller *et al.*, (2005), Patel *et al.*, (2015), and Edelhoff *et al.*, (2016).

In this study, i focused on one migratory species – White eared kob in the Boma-Gambella landscape and one resident species Roan antelope in the Gambella region of Ethiopia.

Having the concept on home ranges in mind, the home ranges for the two-target species were computed using the *adhabitatHR* package for analysis of animal movement data - a package fitted to the open source statistical software R version 3.3.2 and run on RStudio version 1.0.36 environment based on Clement (2016) methods. First, the space usage of the animal commonly called the utilization distribution or utilization density was computed using the relocation XY GPS fix data. The result is a continuous raster grid cell layer which is derived by placing an Epanechnikov's Kernel function (most efficient Kernel estimator and default to *adehabitatHR* package) over each of the relocation fixes and then by averaging together the values from each function.

Epanechnikov's Kernel function

$$K(x) = \frac{3}{4} (1 - x^t x) \text{ if } x < 0 \text{ or } 1 \text{ otherwise}$$

Therefore, the Kernel estimation of the **utilization distribution (UD)** at a given point x of the plane is obtained by:

$$f(x) = \frac{1}{nh^2} \sum_{i=1}^n K \left\{ \frac{1}{h} (X - X_i) \right\}$$

Where \mathbf{X} is a vector containing the coordinates of a point on the plane, \mathbf{h} is the smoothing parameter, \mathbf{n} is the number of relocations, and \mathbf{X}_i is the i 'th relocation of the data frame. The \mathbf{h} parameter controls the width of the Kernel placed over each point.

In principle, the UD hints the potential space where to relocate the animal in the landscape. Guided by the pattern in availability of essential resources and optimal landscape conditions as well as physiologic requirements of the animal, the animal must temporally and frequently navigate through the landscape. Hence, the 50%, 90% and 95% home ranges indicating from the most visited to the least visited sites were deduced from the UD. To minimize mean integrated square errors (MISE) of the Kernel estimator, the *adhabitatHR* uses the least squared cross-validation (also known as unbiased cross-validation) algorithm (LSCV).

The Kernel density ranges (50%, 90% and 95%) could be interpreted as the area in which the animals have spent as a 50, 90 and 95 percent of its time throughout the tracking period, respectively.

2.4.3. Wildlife core areas

The core areas were extracted by interpolating the three years of aerial survey datasets that have similar temporal parameters and survey protocols. A cumulative encounter rates were computed based on each observation during the aerial surveys after harmonized them with the total survey efforts (GPS tracks) undertaken and a quarter degree grid cells. As explained by Rangvald *et al.*, (2009), a quarter degree grid cell is a way of dividing the latitude and longitude degree square cells in smaller squares to form a system of detail geodes. The encounter rates were then interpolated for the whole survey blocks using inverse distance weighting method in QGIS.

2.4.4. Detecting disturbances on wildlife through overlay and trajectory change point analysis

A path segmentation approach using a time-series analysis was applied to trace points in time where significance changes in movement pattern occurred (Edelhoff *et al.*, 2016). Prior to this, a conflict hotspot mapping with an overlay and spatio-temporal analysis with the movement trajectory layer was carried out. Tracking data that have temporal and spatial overlap with conflict hotspots were chosen first to detect change points. Other things (e.g. vegetation greenness and effect of fire) being constant, the underlying cause for the significant change in movement trajectory for the migratory kobs is assumed to be the armed conflict in South Sudan.

The data on selected environmental cues such as NDVI and wildfire were statistically analysed to detect the onset of back and forth migration routes and projected arrival dates to breeding grounds in Gambella National Park based on Marilyn *et al.*, (2012).

Any deviation in the pattern of arrival dates to breeding grounds despite favourable environmental cues could be attributed to the influence of the conflict in South Sudan. The datasets were first cleaned to reduce biases due to early malfunctioning of collars and resident animals in the safe conflict free areas of the landscape.

3. RESULTS

Results obtained from the analysis of aerial survey and telemetry data are presented in the following five sections.

The first section describes the trends in the abundance and distribution of White eared kob and Roan antelope populations in the Boma-Gambella landscape. The recordings made during aerial survey efforts are presented in the form of statistical tables, graphs and maps. The second section elaborates the detailed movement and migration patterns, as well as the Kernel density estimates of home ranges for the collared white eared kobs and roan antelopes. The third section presents the results of core area interpolations of the aerial survey data aggregations for the target species.

The fourth section deals with the analysis of major threats and disturbances on the species under investigation. In this section, i scrutinized the results mentioned and present the statistical and overlay analysis results of detecting the correlation between conflict hotspots and agricultural investments. The impact of armed conflict, settlement expansion, and agriculture on the target wildlife species are presented.

In section five i have presented the protected areas coverage and governance gaps in the landscape and highlighting the opportunities for diverse protected area systems including community conservation and transboundary conservation areas.

3.1. Trends in the abundance and distribution patterns

3.1.1. White eared kob

White eared kobs were found to be the most widely distributed wildlife species in the landscape. The total population of White eared kobs in the Boma-Gambella landscape is estimated to be around a million. Based on the 2013 wet season survey estimates, when there is no migration, the resident kob population in Gambella NP and its surroundings is estimated around 50,000 individuals. The latest dry season (2015) white eared kob population estimate was computed to be around 450,000. From this, it could be concluded that, at least 400,000 kobs seasonally forage for resources between Boma-Bandingilo in South Sudan and the Gambella landscape in Ethiopia. As a

result, there is a wide difference in the abundance and distribution of this species in both landscapes between the dry and wet seasons.

The rapid aerial reconnaissance survey mission of 2009 broadly highlighted the areas where major species are concentrated with White eared kobs dominating the encounter rates. In the 2009 reconnaissance flights 29,685 kobs were counted in 169 sightings (Fig. 4). The 2010 and the four aerial surveys since then applied a consistent survey protocol and coverage. Compared to the 2009 counts (29,685), the 2010 dry season survey encountered lesser observations (16,913). But, distribution wise the 2010 survey results indicate a wider population distribution in the landscape, with a considerable extent outside of the existing protected areas. The 2013 dry season survey efforts produced the same population distribution, but larger population estimate (351,116) than earlier survey efforts.

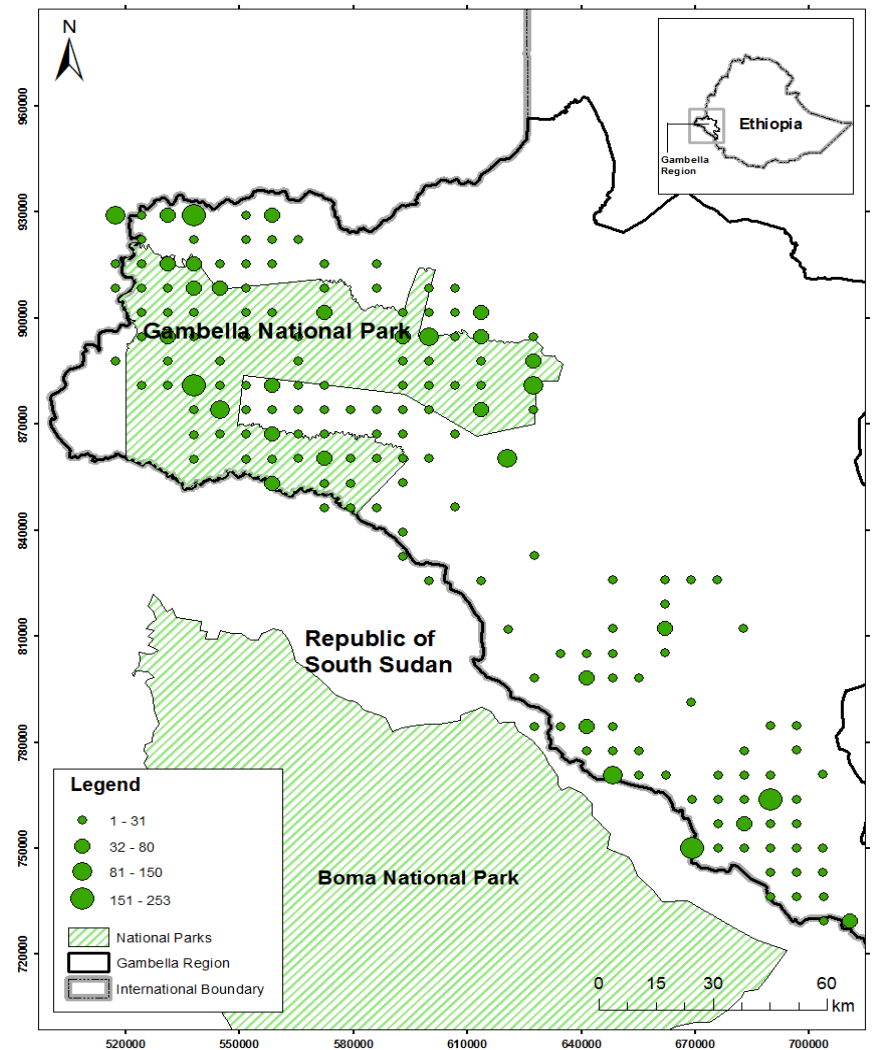
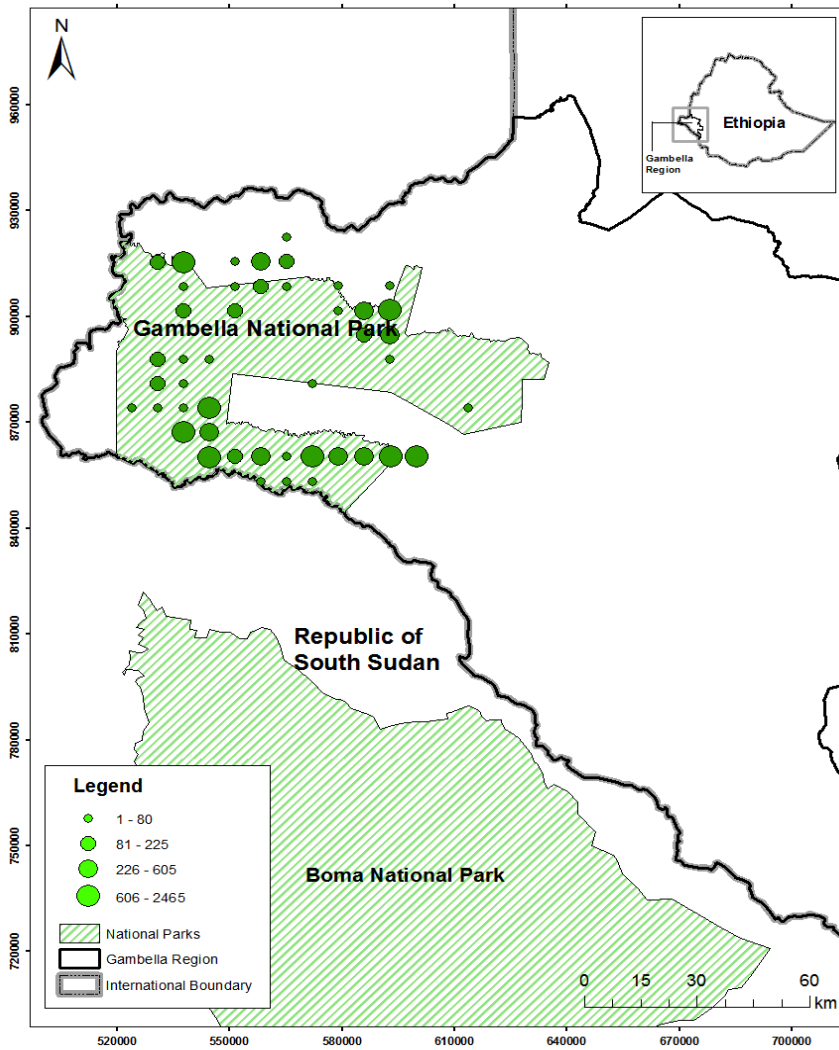


Figure 4 Distribution of White eared kob per quarter degree grid cells based on the 2009 (left) and 2010 (right) dry season survey efforts

The 2015 aerial survey efforts in the core block produced the larger population estimate (399,299) than all other previous aerial survey efforts. Whereas, the population estimate in the southern block (29,169) was the smallest of all survey efforts. The aggregated data from the entire calibrated aerial sample surveys (2010-2015) with similar survey timing (dry season) and protocol indicates that, there is an increasing trend of White eared kob population (Table 1).

Table 1 White eared kob population estimate of 2010 – 2015 dry season aerial SRF surveys

Survey Zone/Year	2010	2013	2015
Core	203,181	292,688	399,299
South	51,962	58,479	29,169
Combined	255,143	351,167	428,468

Moreover, the overall distribution pattern of kobs based on the 2015 survey shows a southward latitudinal displacement than the earlier survey (Fig.5). This was further confirmed with the field observation in mid-March 2018; during which i found no kob around the corridor, except few hundred around Kankan village some 35km west of Metar town. Instead, thousands of Fullata livestock were observed around the corridor.

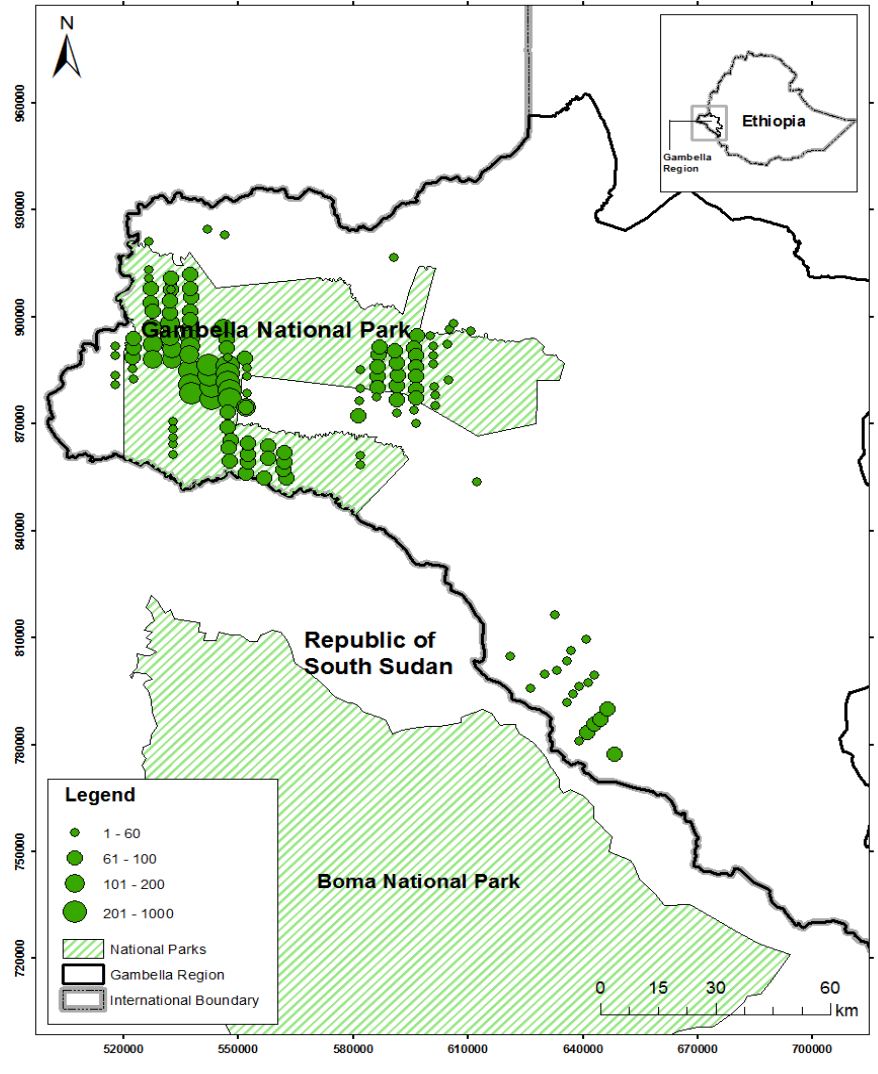
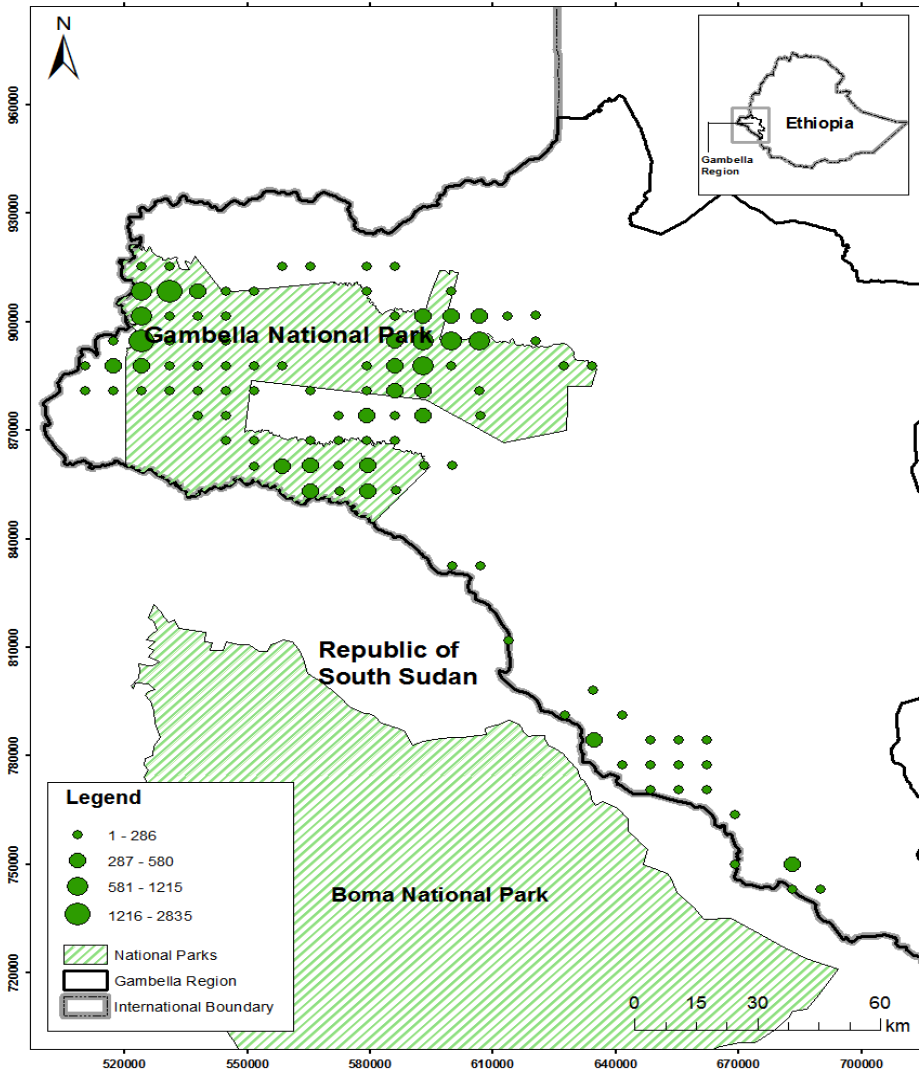


Figure 5 Distribution of White eared kob per quarter degree grid cells based on the 2013 (left) and 2015 (right) dry season survey efforts

3.1.2. Roan antelope

The Gambella region hosts an estimated 2,406 Roan population (Table 2), which are the eastern most remote populations of the tropical humid savannah belt range stretching from Guinea-Bissau to Ethiopia.

Table 2 Roan antelope population estimates based on aerial surveys during 2010 – 2015.

Survey Zone/Year	2010	2013	2015
Core	1287	34	542
South	0	0	1864
Combined	1287	34	2406

The distribution of Roan population in Gambella landscape indicates that, this species is mostly residing outside of the current extent of the Gambella National Park. The 2015 dry season survey uncovered that, contrary to the distribution pattern of other species, the Roan antelopes were more concentrated in the southern survey block (1864 km²) than the core area survey block (Fig.6).

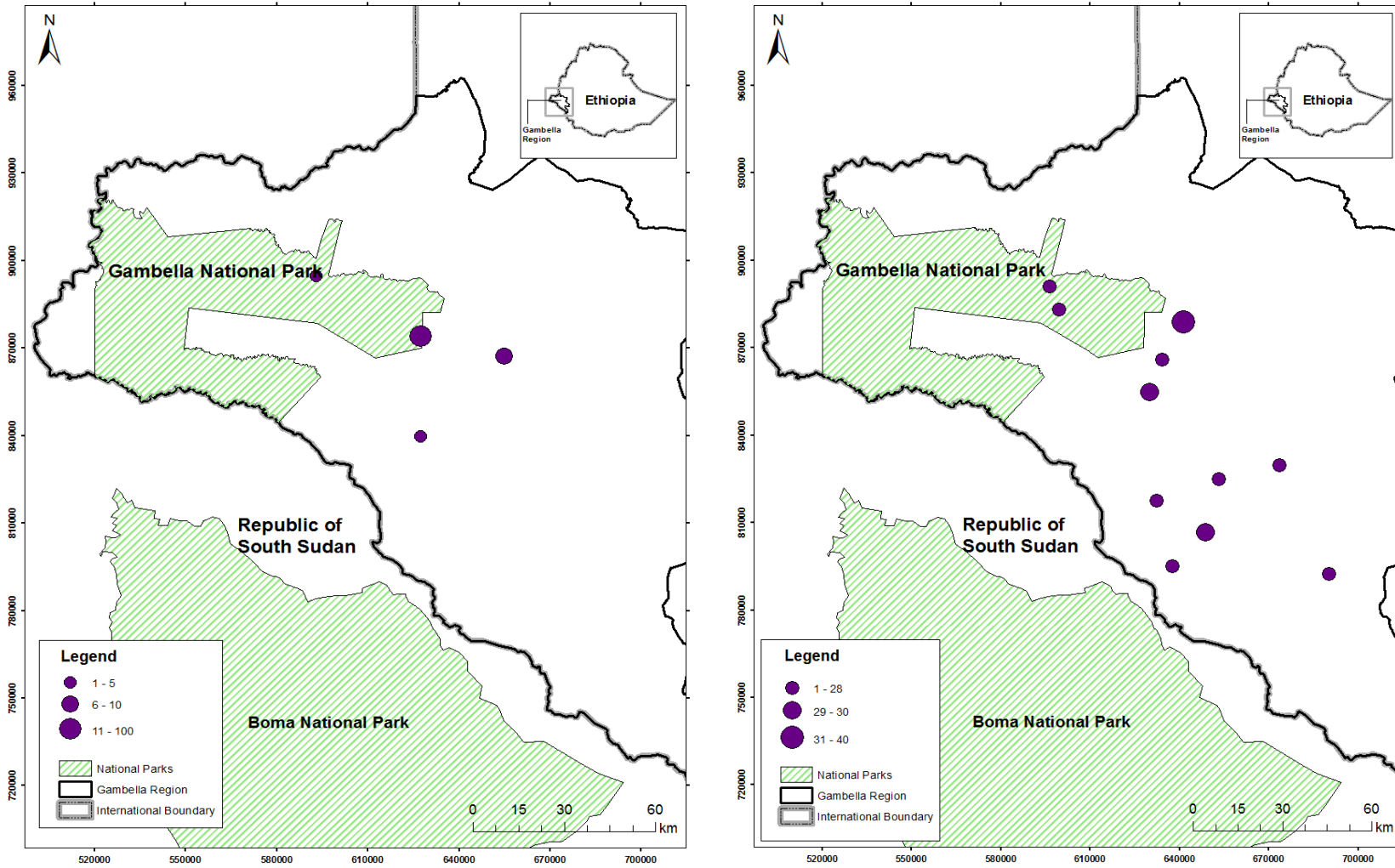


Figure 6 Roan antelope population distribution during the 2010 (left) and 2015 (right) aerial surveys

3.2. Movement ecology and home ranges

3.2.1. White eared kob

The telemetry data analysis result indicates that, out of the total of 64 (35 females and 29 males) white eared kobs fitted with satellite GPS collars, 43 (67%) and 13 (20%) were found to be migratory and resident, respectively. Eight collars malfunctioned within two months after they were installed; hence they were excluded from the analysis. I found four movement patterns and orientations of the migratory white eared kobs. The first, northern route, started from Gambella NP then goes to the west and then heads north up to north east of Barriak village (10 km south of Abwong town), in South Sudan – and then back to Gambella National Park.

Only three out of the 43 migratory kobs used the northern route (Fig.7).

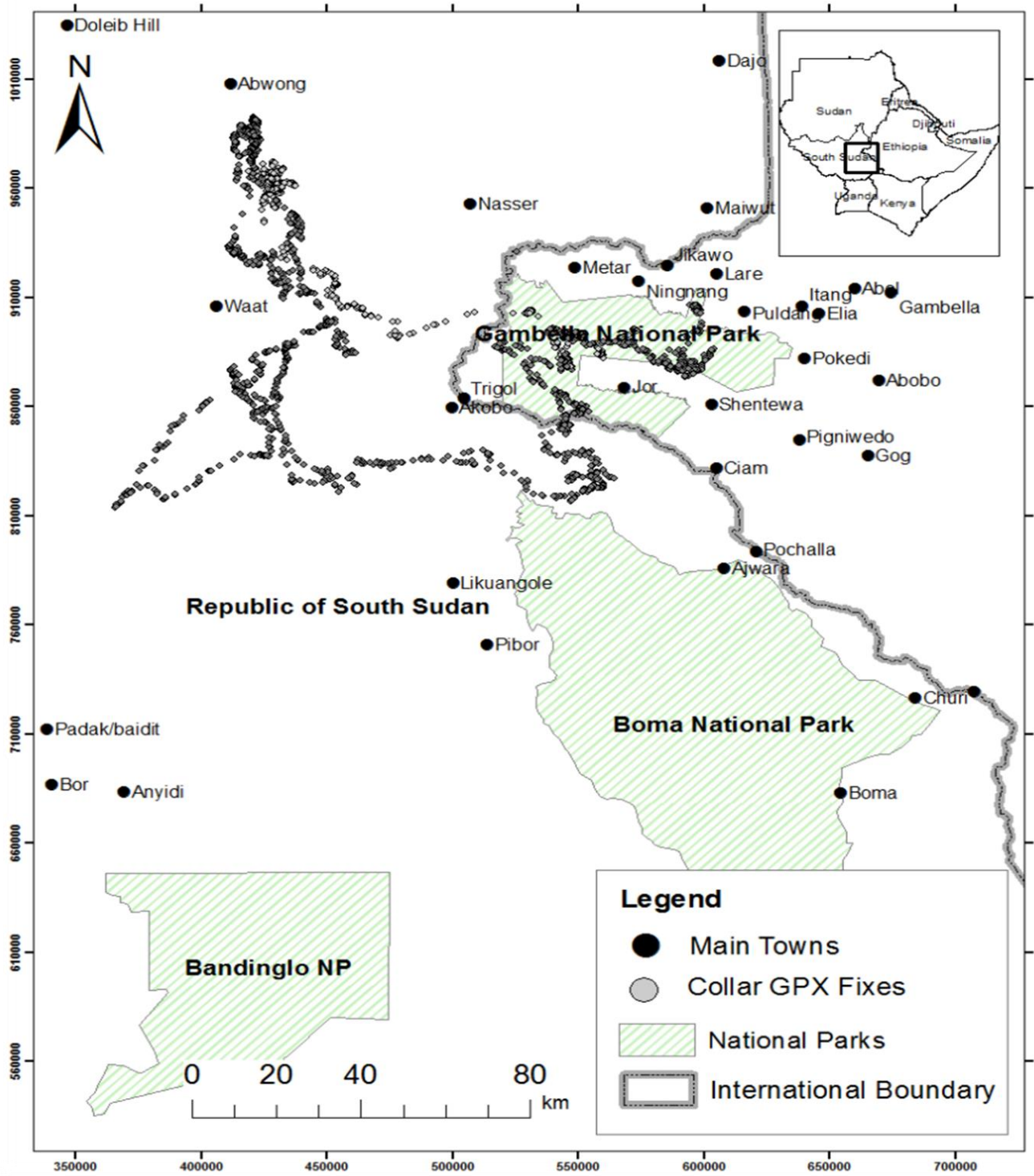


Figure 7 Orientation of the north heading white eared kobs migration route

The second route started from Gambella National Park then orientates to the west and then to the south avoiding the settlements along the Baher-el Jebel River by some 10 km distance to the west and the Murle land to the east then heading direct to Bandingilo National Park and then back to Gambella NP. Four collars went through the second route managed to reach Bandingilo NP (Fig.8).

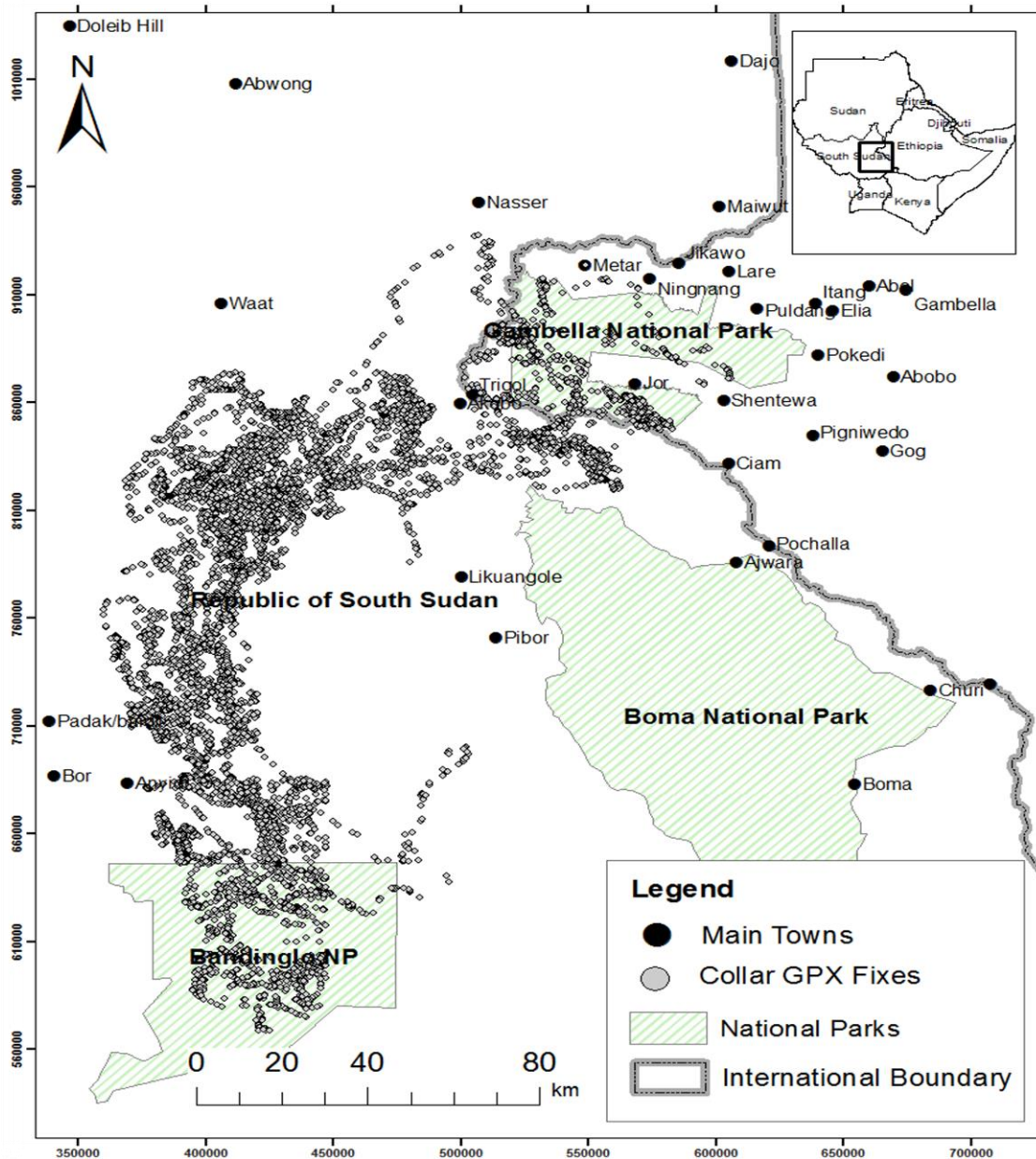


Figure 8 Orientation of the south heading white eared kob migration route

The third route shares most of the segments of the south heading routes, except its advance forward to reach to Boma National Park and then to Gambella NP. Most of the kobs that follow the third route orientation were cut short or returned before they reach Boma NP, except one collar which managed to cross Boma NP on its way to Gambella NP.

A kob fitted with GPS CollarID NAN59 managed to make almost a complete loop route covering both the dry and wet season ranges in both Ethiopia and South Sudan. I calculated that, the total distance covered by this collar was 2027 km. It took 13 months from mid-April 2015 to Mid-March 2016 to complete the route. After strictly smoothing the overlapping tracks, the total track length was calculated to be exactly 860 km (Fig.9).

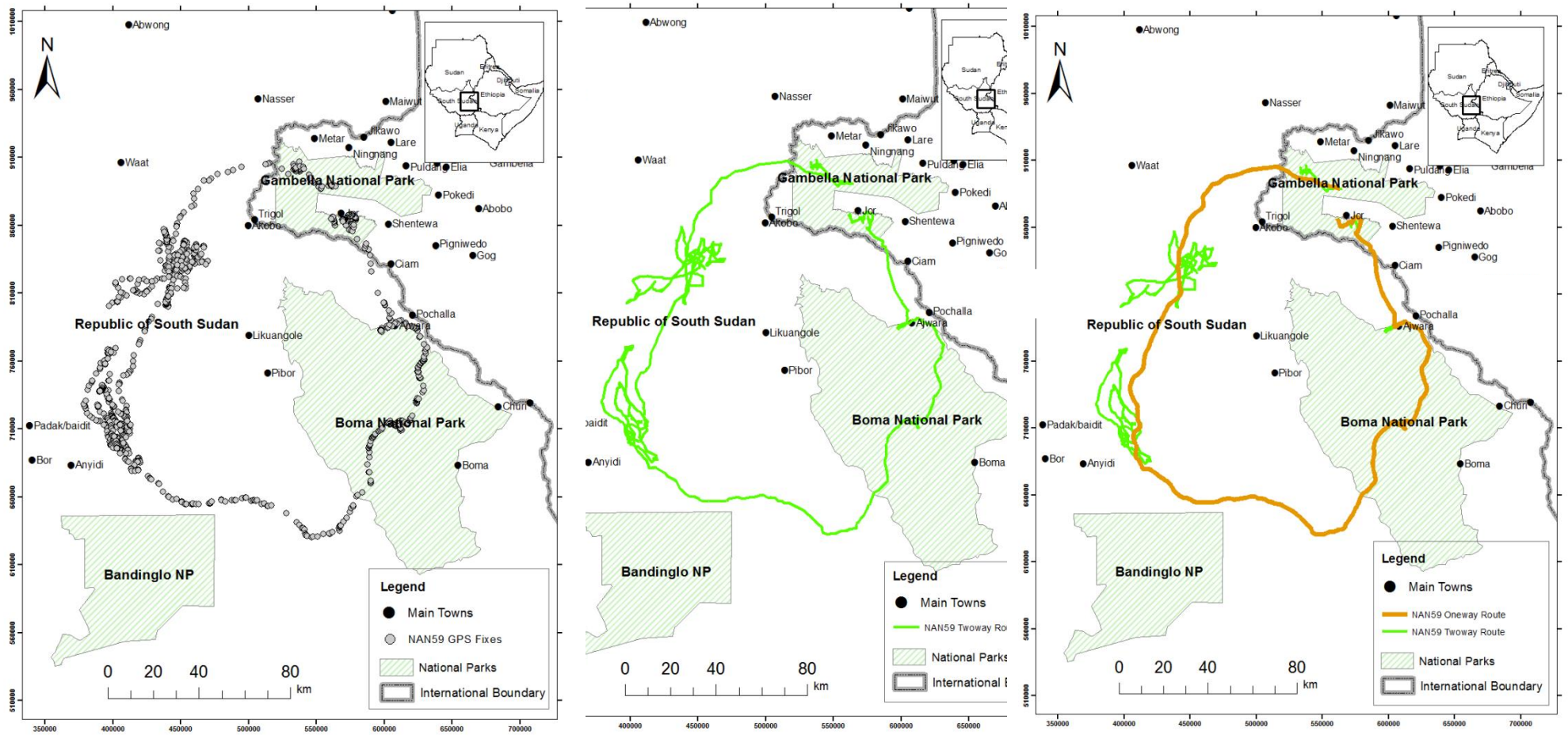


Figure 9 The GPS fixes and smoothed movement route (right) of white eared kob fitted with GPS CollarID NAN00059 during the period April 2015 to March 2016 overlaid on home range extents (left and middle).

The fourth route white eared kob migration starts from lower Akobo River areas in Gambella region of Ethiopia then heads to the west and southwest crossing the Boma NP and heading up to Bandingilo NP, avoiding most of the central parts of the Pibor and Pachala counties (Fig.10).

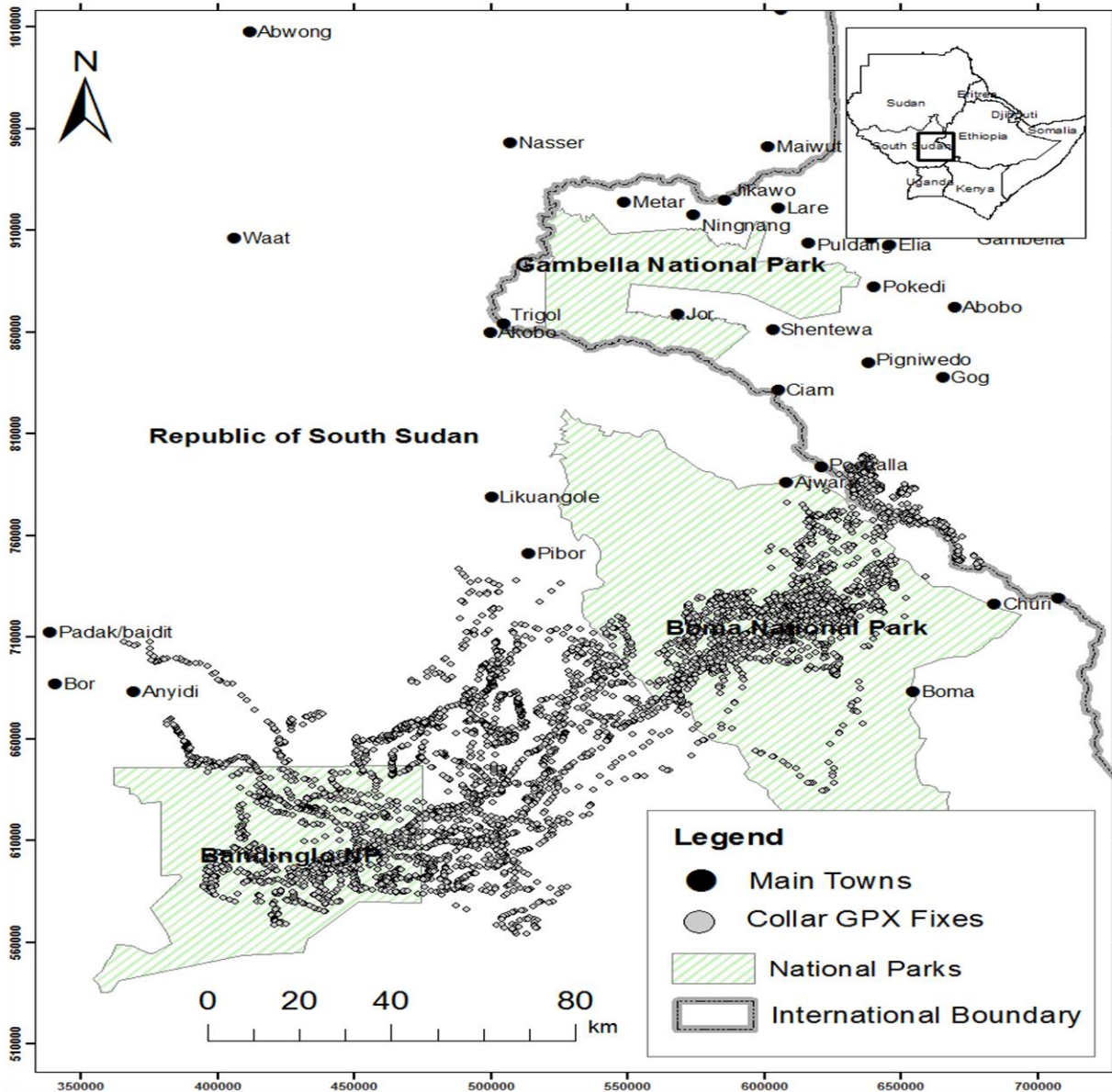


Figure 10 Orientation of the lower Akobo River – Bandingilo white eared kob migration route

Based on 95% Kernel density estimate, the total home range size of the migratory white eared kobs in the Boma-Gambella landscape is estimated to be 73,891 km²; of which 19% (14,019 km²) and 81% (59872 km²) were found to be in Ethiopia and South Sudan, respectively. Most of the home ranges and migration routes of white eared kobs were found to be outside the existing protected areas. Only 24% of the total home range overlaps with the existing protected areas systems – Gambella NP (6%), Boma NP (10%) and Bandingilo NP (8%). About 13% and 63% of the total range in Ethiopia and South Sudan, which represent 67% and 78% of the range in these countries, respectively is not yet protected (Table 3). The largest unprotected range in South Sudan extends north from the edges of Bandingilo and Boma NPs up to the northeaster periphery of the Sud swamps till the Ethio-South Sudan boarder around Trigol (Akobo Ethiopia) village.

Table 3 White eared kob home range statistics for the Boma-Gambella population between Ethiopia and South Sudan.

Home Range Category	Area (km ²)	% of Total Range	Remarks
Boma-Gambella Landscape	73891	100%	Using 95% KDE limit
Ethiopia	14019	19%	
Gambella National Park	4575	6%	
Range Outside of Protected Areas (Ethiopia)	9444	13%	Represents 67% of the range in Ethiopia
South Sudan	59872	81%	
Bandingilo National Park	5867	8%	
Boma National Park	7373	10%	
Range Outside of Protected Areas (South Sudan)	46632	63%	Represents 78% of the range in South Sudan
Total Home Range with in Protected Areas	17815	24%	
Total Home Range outside of Protected Areas	56076	76%	

As depicted in Figure 11, the existing protected areas are not well-designed to secure the home ranges, corridors, breeding grounds and core resource areas of both migratory and resident species. The GPS fixes received from **13** resident white eared kobs have influenced the Kernel density based home range analysis.

Based on a 95% Kernel density estimate, the lower Akobo White eared kob population has a total home range of 14,500 km². The 50% core area (2766 km²) is equally shared between Boma NP and the lower Akobo River areas. The dry season range for this kob population segment in Ethiopia is not yet protected by formal protected area system.

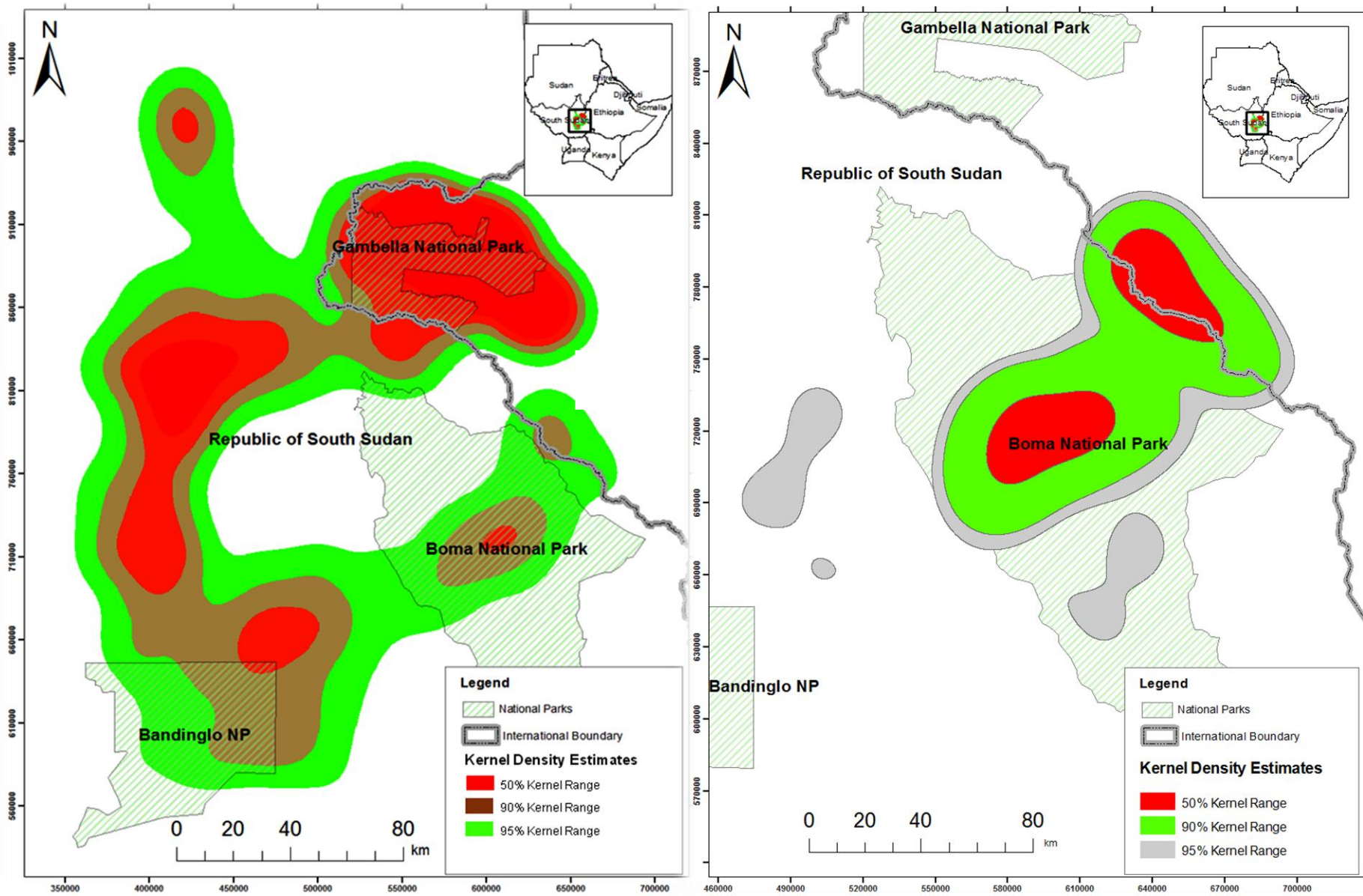


Figure 11 Home range for all the Boma-Gambella population (left) and the lower Akob migratory White eared kob group (right)

3.2.2. Roan antelope

The data from all the six satellite GPS collars mounted in 2015 on six roans (3 females and 3 males) representing three different groups of roan antelopes were considered for the analysis. The first group with three collars (SAT1639, SAT1640 and SAT1642) were tagged around lower Akobo River 15 km south of Pugnido town.

The second group was fitted with one collar (SAT1641) in the south-western edge of Duma wetlands between Saudi Star and Ruchi agricultural concessions. The fifth one (SAT1638) was mounted on a roan representing the group 15 km southwest of Ningnang town. The sixth (SAT1643) was mounted on a Roan 5 km southeast of the Park corridor.

The consolidated result, from the analysis revealed that the Roan antelope forage in the convergence zone between the transitional woodlands and low-lying lush savannah areas. Telemetry based home range analysis of collared Roan Antelopes also produced similar distribution and movement pattern. The roan populations in Gambella have a very restricted movement pattern. The groups remained isolated in both wet and dry seasons moving only within their respective ranges (Fig.12).

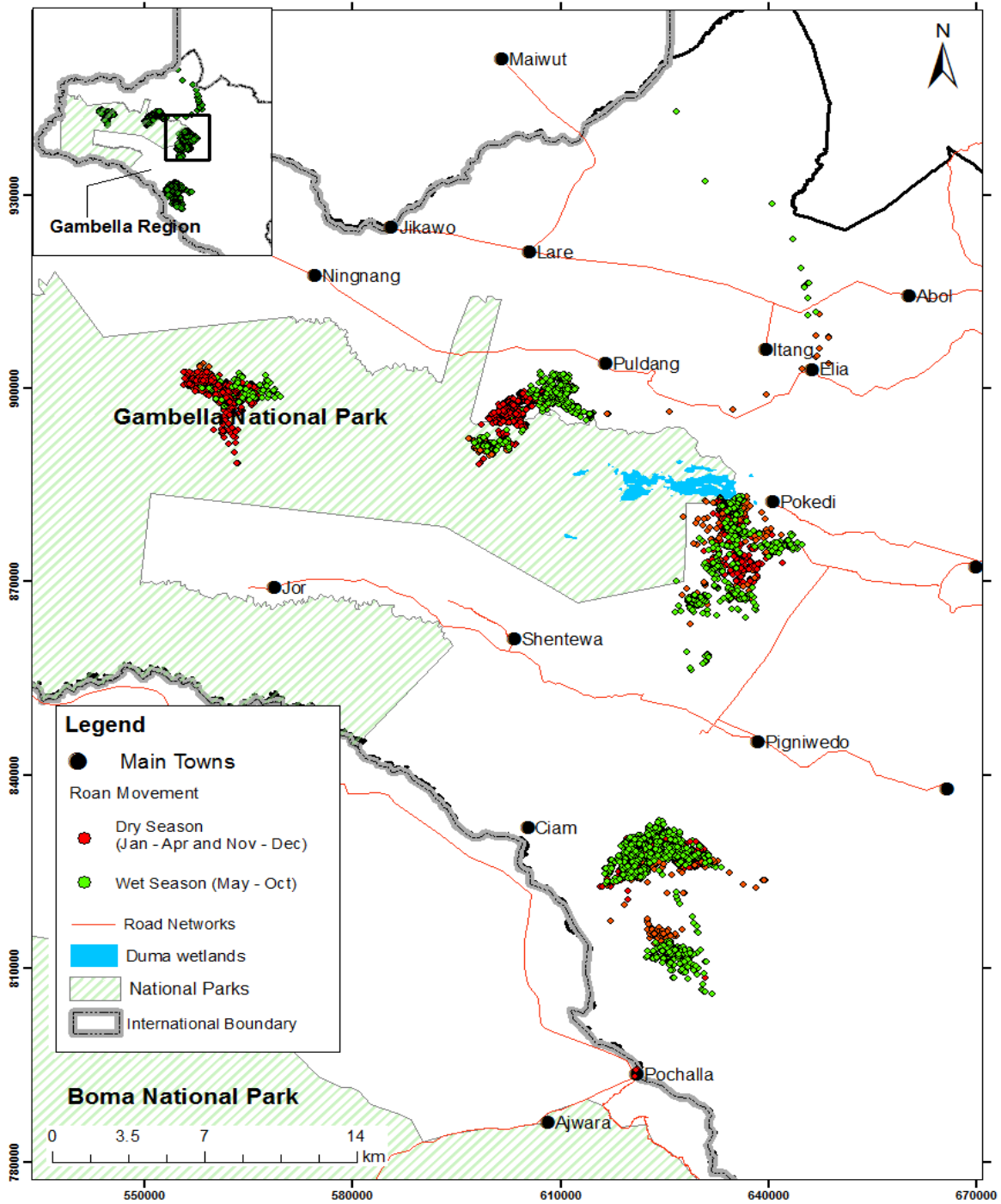
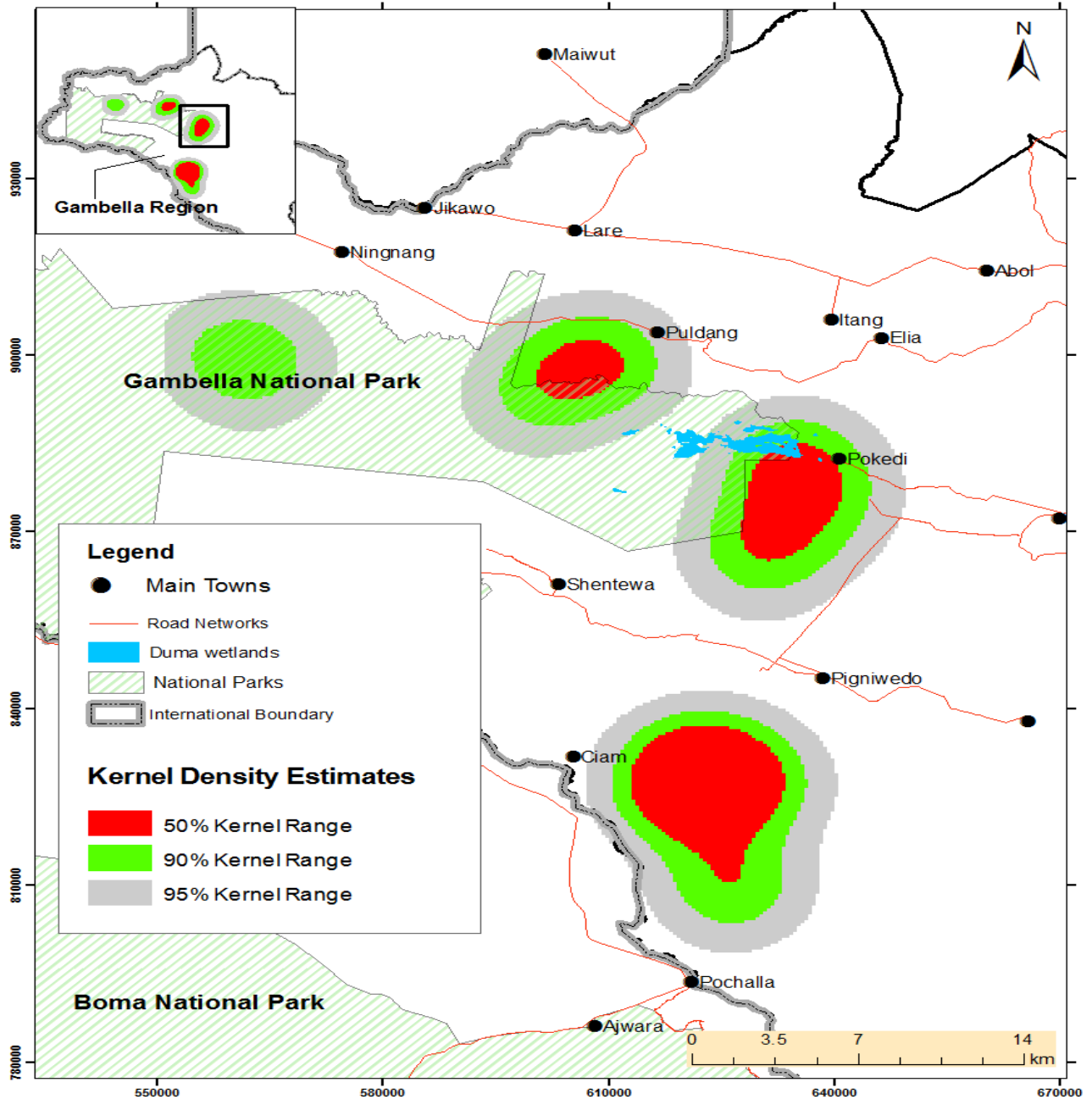


Figure 12 Movement patterns of collared roan antelope during wet and dry seasons

The collared roan groups were found to be isolated from each other with no cross-group movements recorded. Based on 95% Kernel density estimate done for each group, all groups were found to be confined within four separate ranges each having an average range size of 175 km² (Fig. 13).

Figure 13 Home ranges of Roan Antelope in the Gambella landscape



3.3. Core area delineations

3.3.1. White eared kob core areas compared with core areas shared by other key species

The inverse distance weighting algorithm based interpolation of total white eared kob encounter rates indicate that the kob core areas form a U-shaped pattern in Gambella region. The highest encounter rates, up to 83 individual kobs per quarter degree grid cells, were recorded in the area east-west following southern and northern banks of Gilo River heading up to the confluence of Pibor and Baro rivers. Another core area wing heads north from Akobo River following the western edge of the Duma wetlands up to the end of the Park corridor at Baro River (Fig.14). The details of locations in the above core area description include:

- a) Lower Gilo wetlands (around the Oxbow lakes south east of Kankan village) all the way south to the south-western edge of Gambella National Park.
- b) The east-west strip of Gambella National Park strip between Gilo and Akobo rivers and
- c) Perpendicular to (b) above the eastern flank crosses Gilo River northwards avoiding Jor and Shentewa settlements to the west and east respectively; and then spears further north colliding with the Karuthuri agricultural concession on both edges of the Park corridor on its way to reach the Baro River.

Another important white eared kob core area is the former Akobo Controlled Hunting Area in the southeast and east of Pachalla village heading northwest up to Ciam village and north up to southern bank of Gilo River just south of Gog village. The eastern extent of this core area is limited by Gilo River and the western escarpments of the Guraferda Mountains.

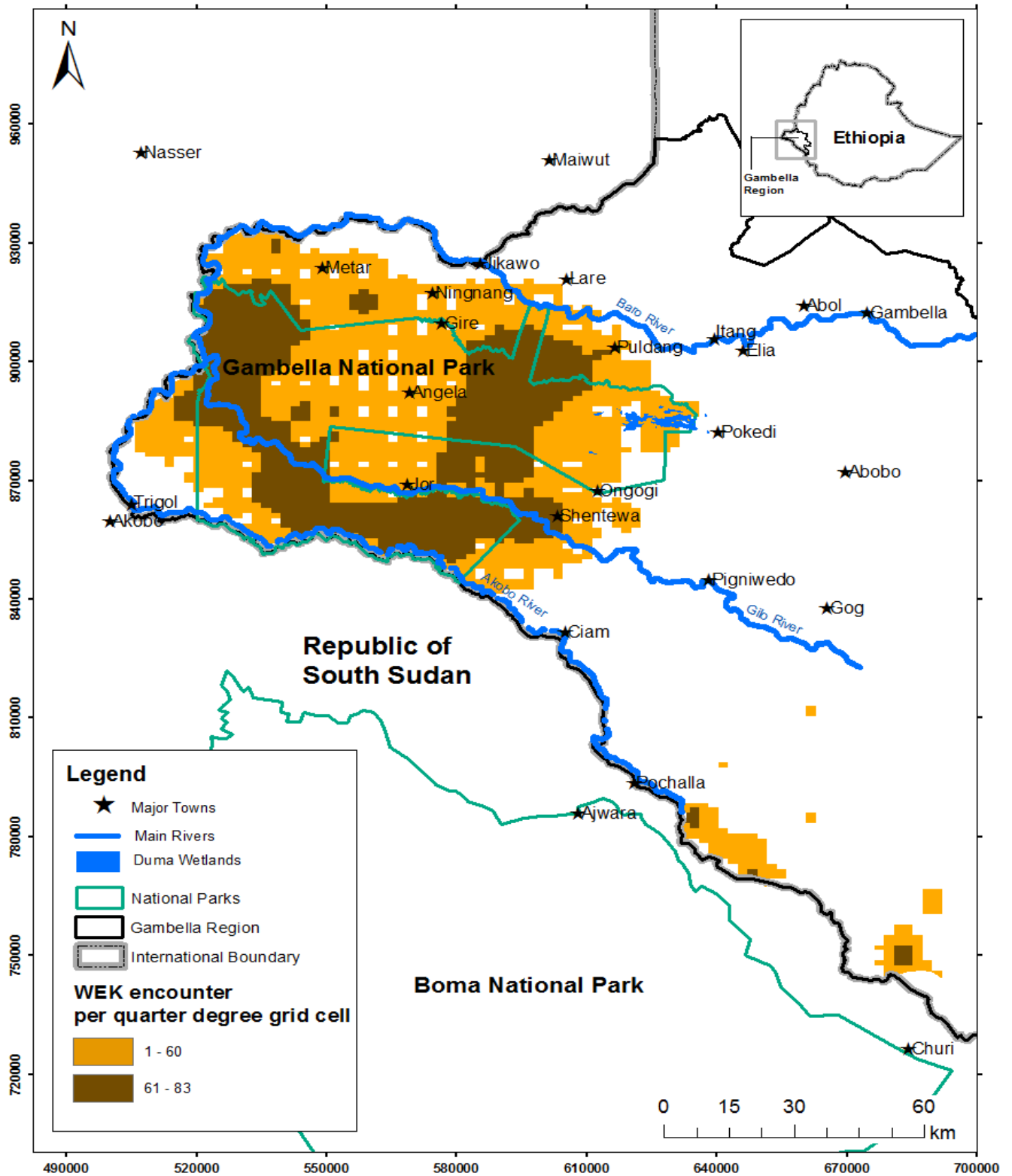


Figure 14 White eared kob core areas using data from all surveys harmonized with survey efforts and quarter degree grid cells (qdgc).

The core areas of all wildlife considered follows the patterns of core areas dictated by white eared kobs (Fig.15).

The gap in the section labelled with “A” is caused by a cumulative latitudinal stretch of disturbance emanating from Jor, Angella and Gire villages (Fig. 19). The first two are Anywa community and the last one is a Nuer community settlement. Jor village is not expanding a lot considering its age due to the flooding and associated disasters from Gilo River. Shentewa village, the former seat of Jor district some 35 km east of Jor village has been gradually abandoned due to flooding from Gilo River; and currently the district has been moved to Ongogi village. As a result, wildlife seems to reclaim the area around Jor village. However, the encroachment and disturbances from the recent Nuer community settlement at Gire backed by Angella village from the south is accountable to create the U-shaped core area picture in the landscape.

There are also new Nuer settlements (e.g. Kankan) along the western course of the Gilo River; posing a danger of cutting the white eared kobs from accessing their north-western most dry season range north of Gilo River.

The area labeled with “B” attributed to the disturbance and the influence of Anywa settlements and their livelihoods of recession with Slash-and-burn agriculture, namely the Pugnido town and Pachalla Ethiopia villages in combination with a change in habitat type *Cumbertum-Terminalia* Woodland. Pugnido is the largest town next to Gambella town in the region. It has one of the oldest refugee camps in the region currently hosting 85,000 refugees mostly from South Sudan.

The other bottle neck to white eared kob migration in the Boma-Gambella landscape is Tirgol-Pachalla-Ciam-Pugnido block (area labelled with “C”). The western and central parts of this block are inhabited by Lou Nuer and Murle communities. The Murle are ferocious hunters and cattle raiders. They are in a continuous resource and territorial conflict with Nuer and Dinka in the north and west, with Anywa in the east, with Jiay, Kachipo and Toposa communities in the south.

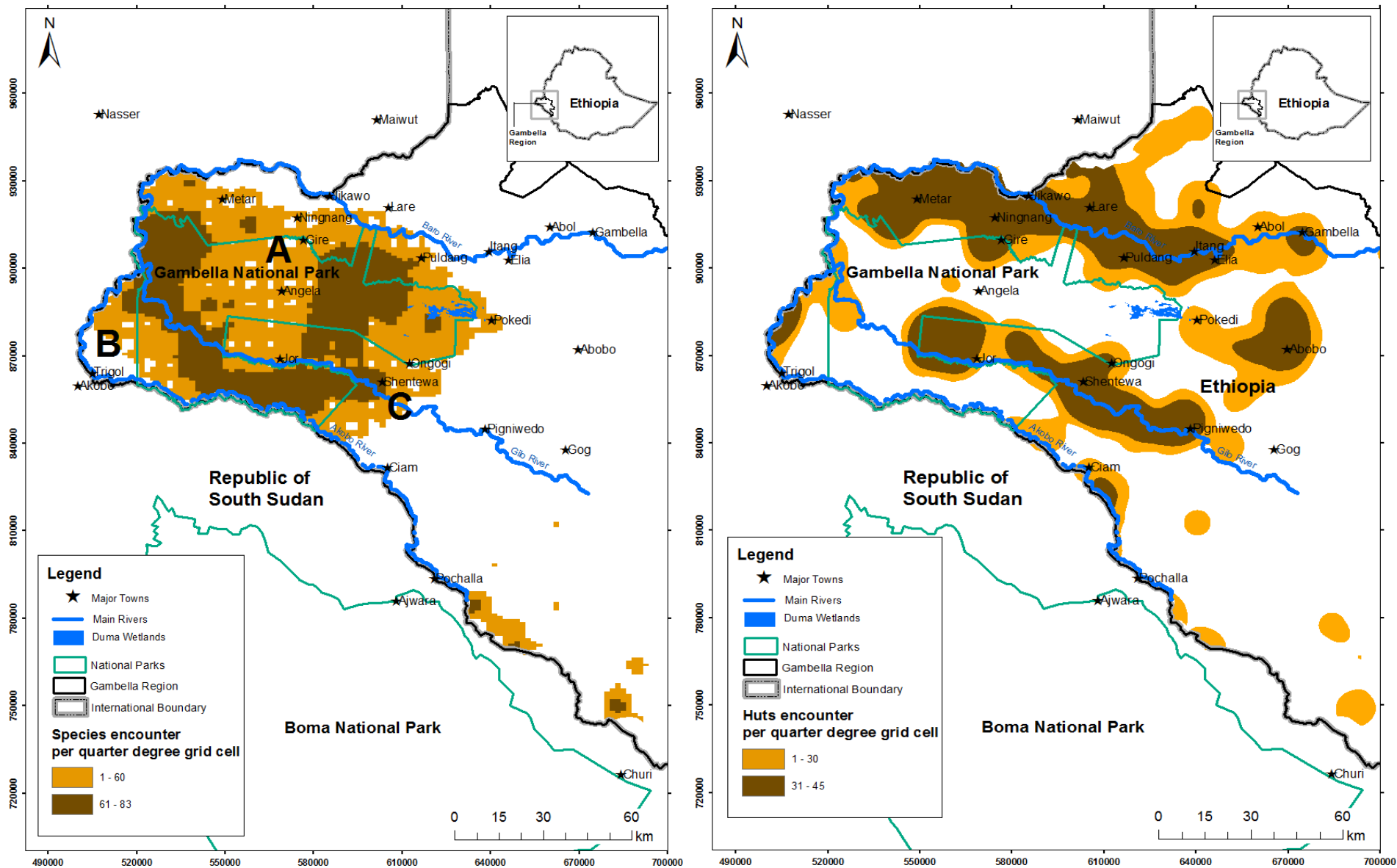


Figure 15 Key wildlife core areas (left) and settlement encounter rates in Gambella region with conservation gaps (right)

3.3.2. Roan antelope core areas

Roan antelopes are concentrated in the eastern edge and peripheries of Gambella NP along the *Cumbertum-Terminalia* belt with few other isolated patches in the Park. Almost two-third of the core areas of roan antelopes in Ethiopia are outside of formal protected areas (Fig.16).

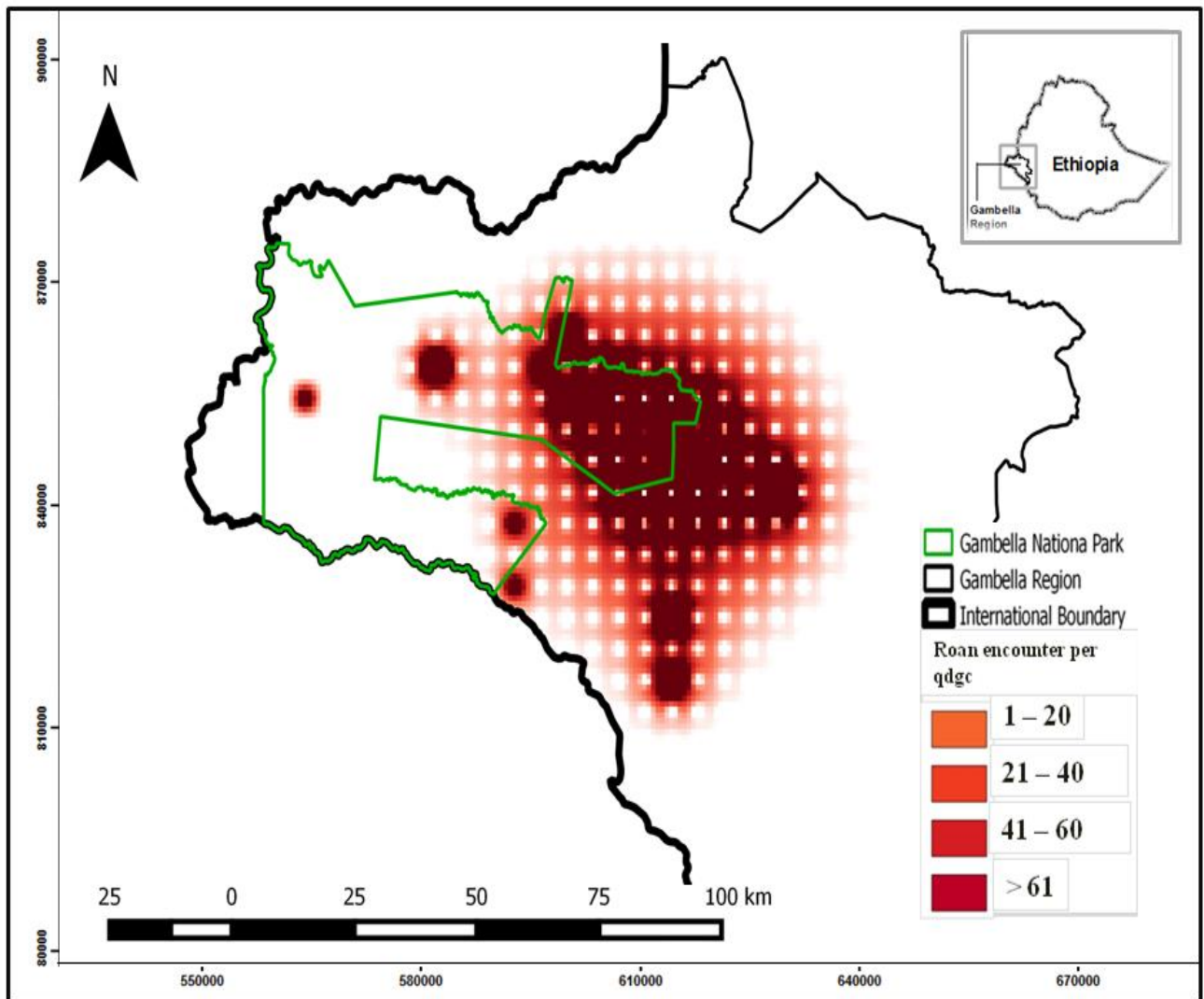


Figure 16 Roan antelope core areas using data from all surveys harmonized with survey efforts and quarter degree grid cells.

3.4. Threats and their disturbance on the target species

3.4.1. Major conflict hotspots and their disturbance on white eared kob migration

The landscape is a swamp ecosystem, where during the wet season (May-October) water overflows up to half a metre above the ground favouring growth of up to 3 m long and dense elephant grass (*Pennisetum purpureum*); making visibility and movement almost impossible. During the dry season (November – April), the drying and dying grass creates a high biomass combustion promoting fire and hence in a very short period almost the whole landscape, except Jongeli and the Easter Gambella highlands, turns into vast open and accessible landscapes. This allows fighting factions to mobilize their human and machinery tools to the low-lying battle grounds. A total of 2100 conflict hotspots were reported in South Sudan between the years 2013 to 2016. The recent conflict in South Sudan started during the last two weeks of December 2013. The general overlay analysis of the major conflict hotspots and the movement pattern of collared species before and after the outbreak of the conflict indicate that the migratory white eared kobs have responded to the major conflict hotspots by displaying longitudinal and latitudinal displacements. The light brown and green dots on the map are points indicating collared kob movement before and after the outbreak of the conflict in South Sudan, respectively.

The northern route has been completely abandoned after the outbreak of the conflict. The white eared kob movement around the Bor-Waat corridor, where most of the intense fighting occurred, has been shifted further eastwards during the years after the onset of the conflict. The white eared kob movement data overlaps with the major conflict hotspots in the landscape. The result indicates that, for most of the conflict incidents reported, the white eared kobs have responded either by making a sudden longitudinal or latitudinal displacement in their movement patterns (Fig.17).

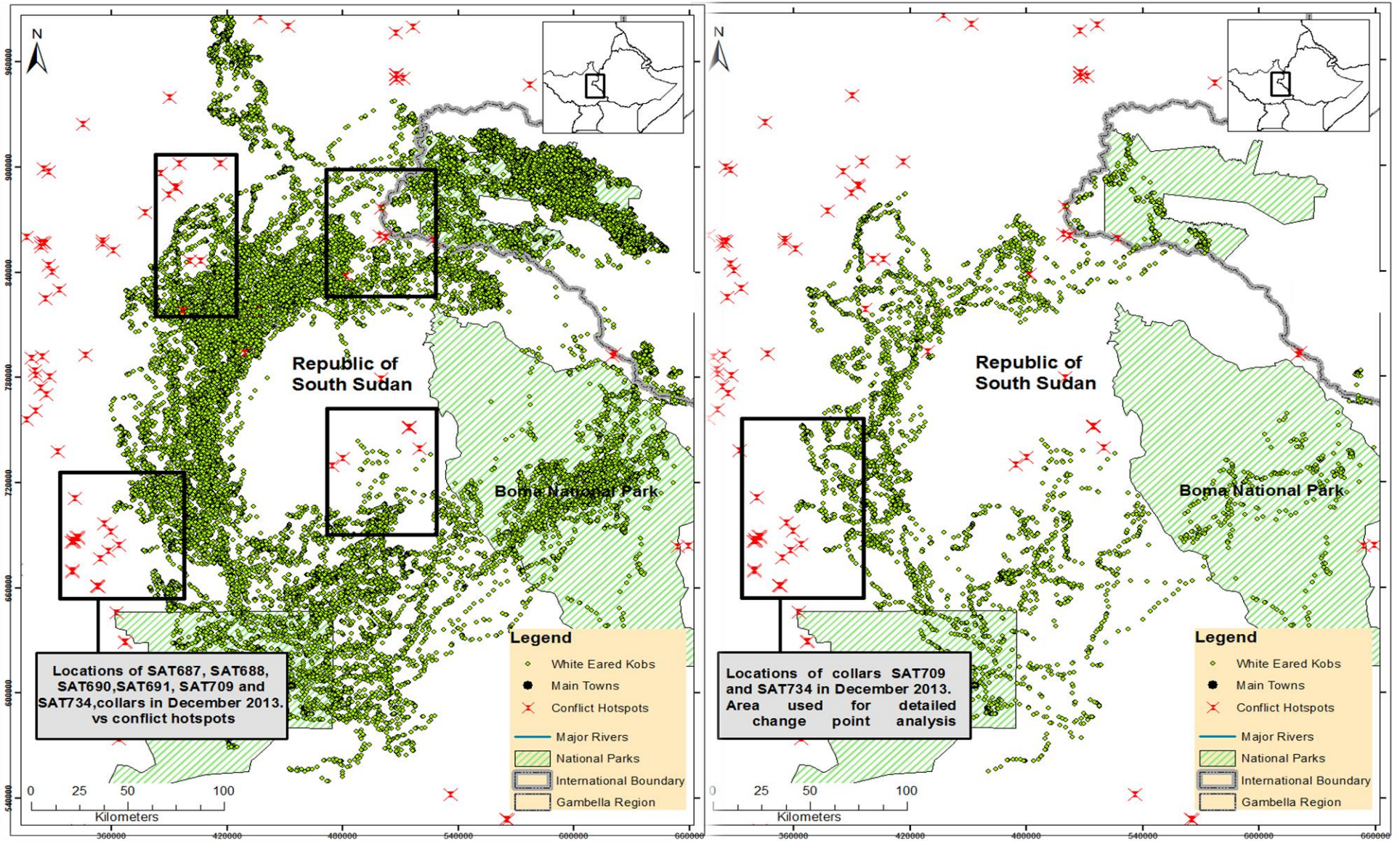


Figure 17 Major conflict hot spots (left) and location of collared kobs used in the overlay and change point analysis (right)

3.4.2. Correlation of white eared kob movement route trajectory change point analysis against major conflict hotspots

The path segmentation analysis uncovered that during the month of December 2013, white eared kobs fitted with collar ID SAT709 and SAT734 displayed a sudden displacement in distances avoiding the areas where intense fighting was reported. This is an indication that, migration was delayed due to the conflict. In normal circumstances, these collars should have been in the Gambella part of the landscape in December. A total of 186 GPS fixes were received from the kob fitted with collar ID SAT709 between 1st and 31st of December 2013. Disregarding displacements below 500 m between GPS fixes, the average displacement was calculated to be 1.8 km per day, the largest displacement recorded was 2.6 km between GPS fixes (Fig.18).

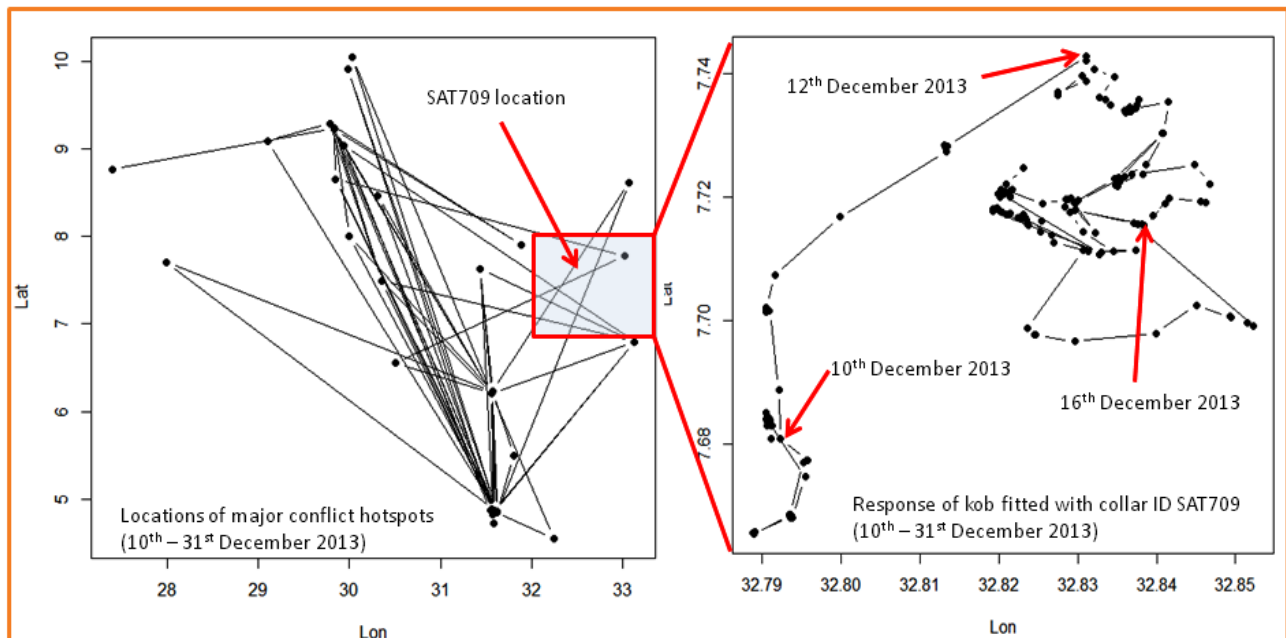


Figure 18 Major displacement points for SAT709 compared to locations of conflict hot spots during December 2013.

The kob fitted with collar ID SAT734, showed more pronounced displacement than the one with SAT709. The same number of (186) GPS fixes were recorded from SAT734 in December 2013. The total distance travelled by this animal during the month was 127 km, with an average displacement of 11 km per day. Disregarding, displacements less than 500m, the average displacement during the month was 4 km per day, with the maximum displacement 8.3 km between GPS fixes.

Intense fighting between government and anti-government factions (Lou Nuer and Dinka) were reported along the Bor – Waat frontline. The GPS fixes from collared kobs, particularly SAT709 and SAT734 were recorded moving in between cross fires. The trajectory segmentation analysis for these two collars uncovered that, they were responding to the disturbances due to the ongoing conflict during that time by showing sudden displacements in location (Fig.19).

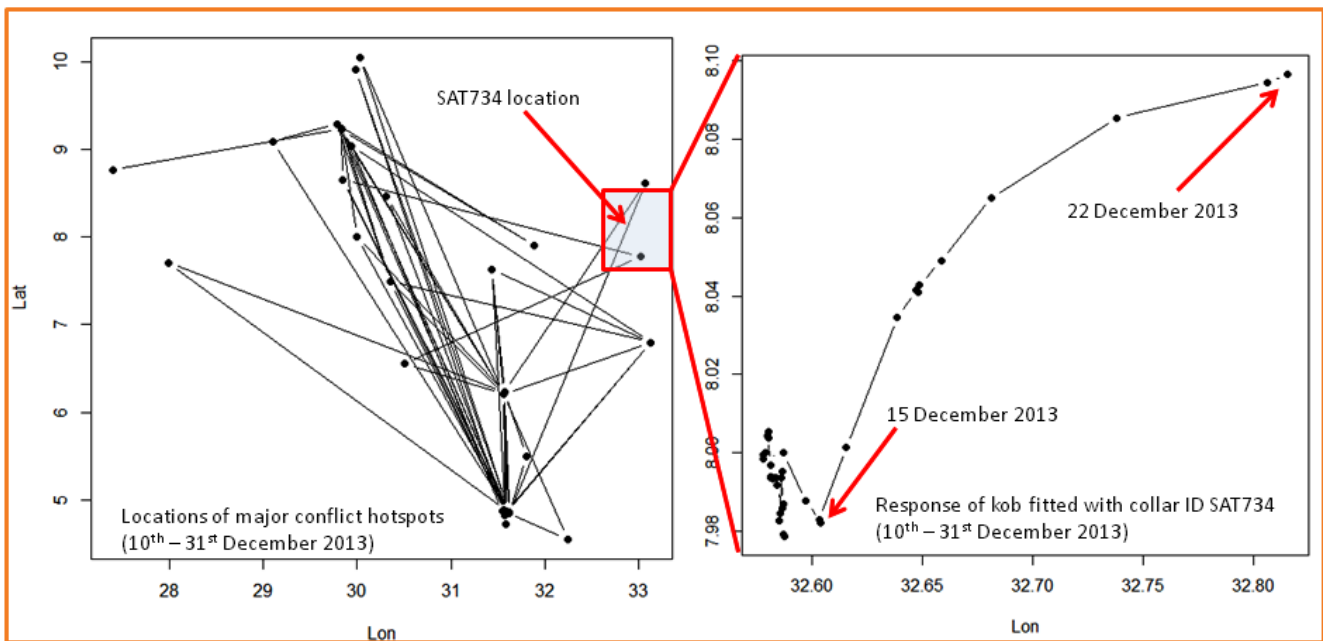


Figure 19 Major displacement points for SAT734 compared to locations of conflict hot spots during December 2013.

3.4.3. Livestock disturbance on Wildlife in the landscape

Human activities such as livestock and commercial agriculture were found to be major agents of disturbances to the roan antelope population in the Gambella landscape. During the dry season, there was a high competition for grazing land between Fullata livestock and ungulates, particularly Roan, Tiang and Lelwel Hartebeest. In all the aerial surveys, livestock population estimates were found to be more than most of the ungulate estimates. The population was estimated to be 18, 377; 87,577 and 93,163 during the 2010, 2013 and 2015 dry season aerial surveys, respectively.

One GPS collar (SAT1643) mounted on a roan antelope was detected moving via the usual route used by Fullata pastoralists. One of the pastoralists might have hunted this animal or retrieved the collar from a dead roan and took it with them crossing Baro River and heading deep into the north-eastern edge of South Sudan. This helped us to track the movement pattern of Fullata livestock indirectly.

During the wet season (May – October), they stay in South Sudan moving through the Malwut, Longochuk, Maban, Melut, and Renk counties of the Upper Nile state in north-eastern South Sudan bordering with the Sudan. During dry season (November to April), they come to Gambella region via the Malwut-Itang corridor entering deep into Gambella National Park crossing the Baro River around Elia village and the Park corridor (Fig.20). Livestock pushes the wildlife south as far as the northern Bank of Gilo River. Nowadays, they could be found everywhere north of the Gilo River except the eastern highlands.

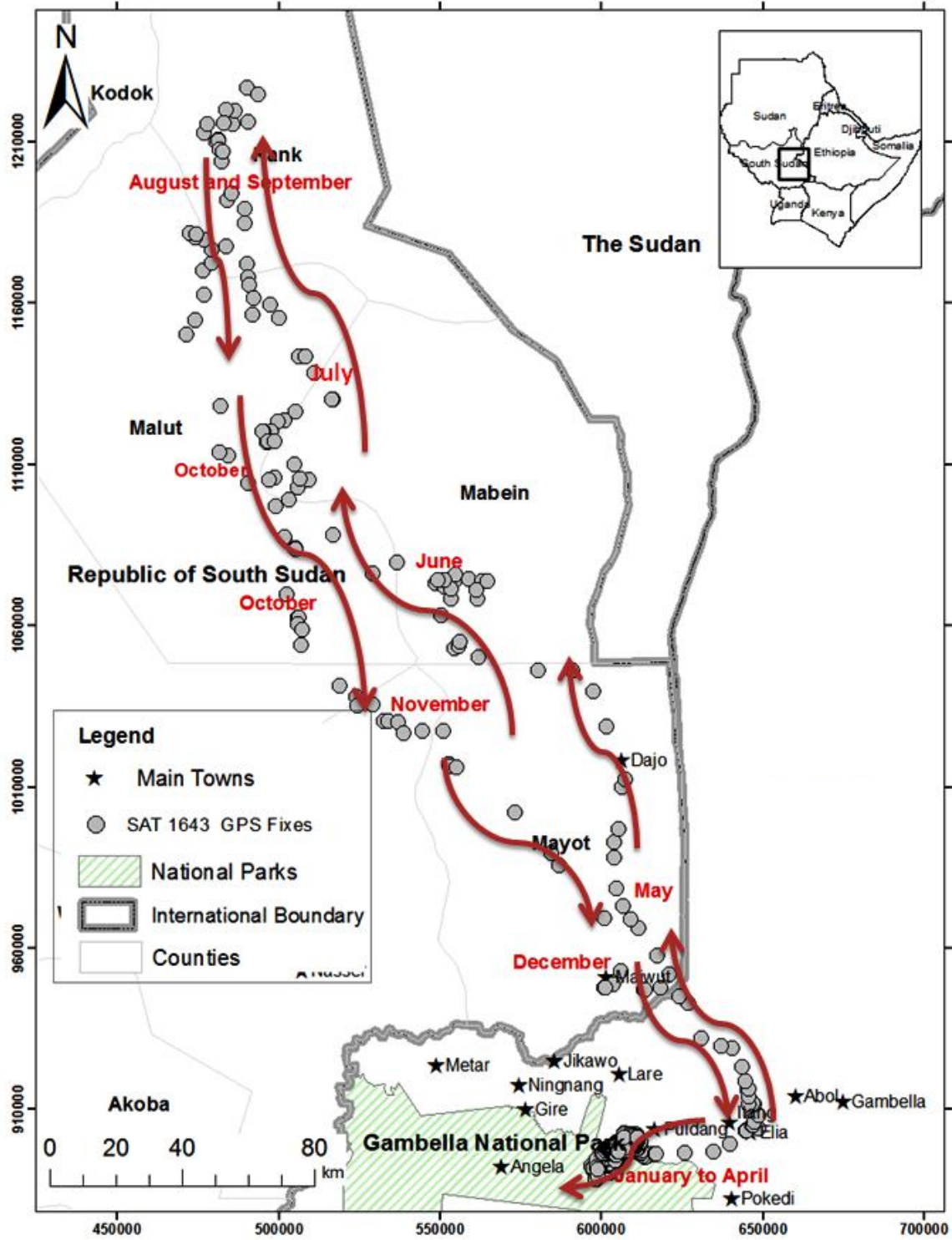


Figure 20 Seasonal movement of stolen Roan collar with Fullata pastoralist

3.5. Environmental Cues – NDVI and Fire regimes

The NDVI stat taken in three sample locations (two in Ethiopia and one in South Sudan) for the period between January to April and November to December 2013 indicates that, there was a sharp decrease in vegetation greenness in the Bore - Padak area of South Sudan than middle Akobo River (east of Pachalla village) and Gambella National Park (Fig.21).

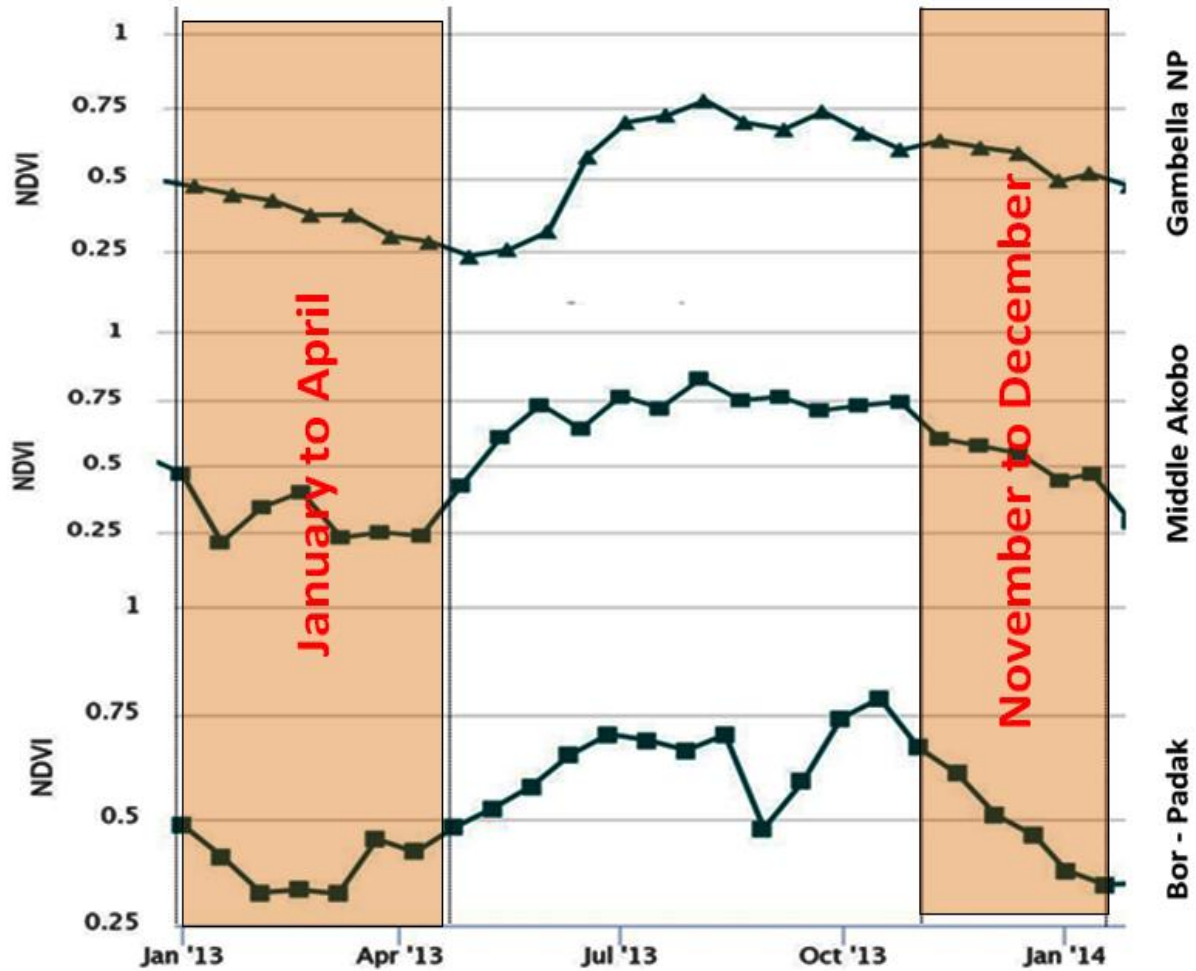


Figure 21 NDVI statistics for three sample locations in the Boma-Gambella landscape, Bor-Padak (bottom), Middle Akobo River (middle) and Gambella National Park (top) during January to April and November to December 2013.

The NDVI stat corresponds with fire regime. Between January and December 2013, MODIS recorded a total of 9456 fire hotspots in the Gambella region. A total 7376 km² of savannah grassland and woodland was burnt in 2013 (Fig.22).

The greenness decreases in the following months promoting ignition of wild fire and consequent regeneration of palatable grasses. Hence, hundreds of thousands of kobs are attracted by the availability of short palatable grasses and water during this time in Gambella (Plate 1). The wet season in Gambella is clearly indicated in figure 28 below with zero fire incidents recorded during the months of May to October.

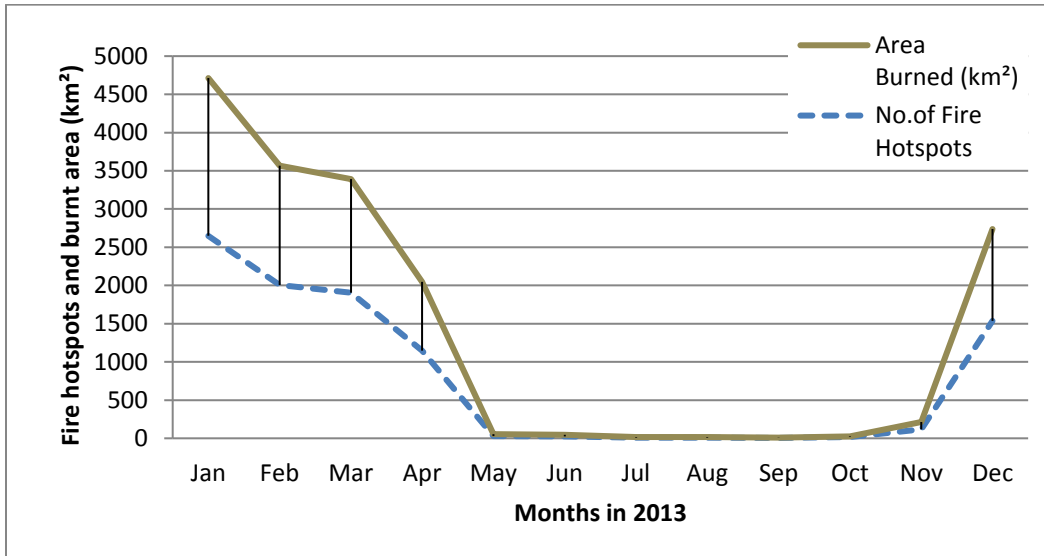


Figure 22 Fire incident counts and burnt areas in Gambella region (January to December 2013)



Plate 2 White eared kobs during peak fire season in Gambella National Park.

Figure 23 depicts the spatiotemporal coverage of fire incidents in the Gambella region. As highlighted with NDVI analysis above, the peak fire season was between the months of December and April. Fire hotspots start flaring in mid-November almost every year. In Gambella region, besides the eastern Afromontane forest in Godere and Dimma districts, the last sites to catch fire (in late April) are the areas around the Oxbow lakes of lower Gilo River and peripheries of Duma Wetlands.

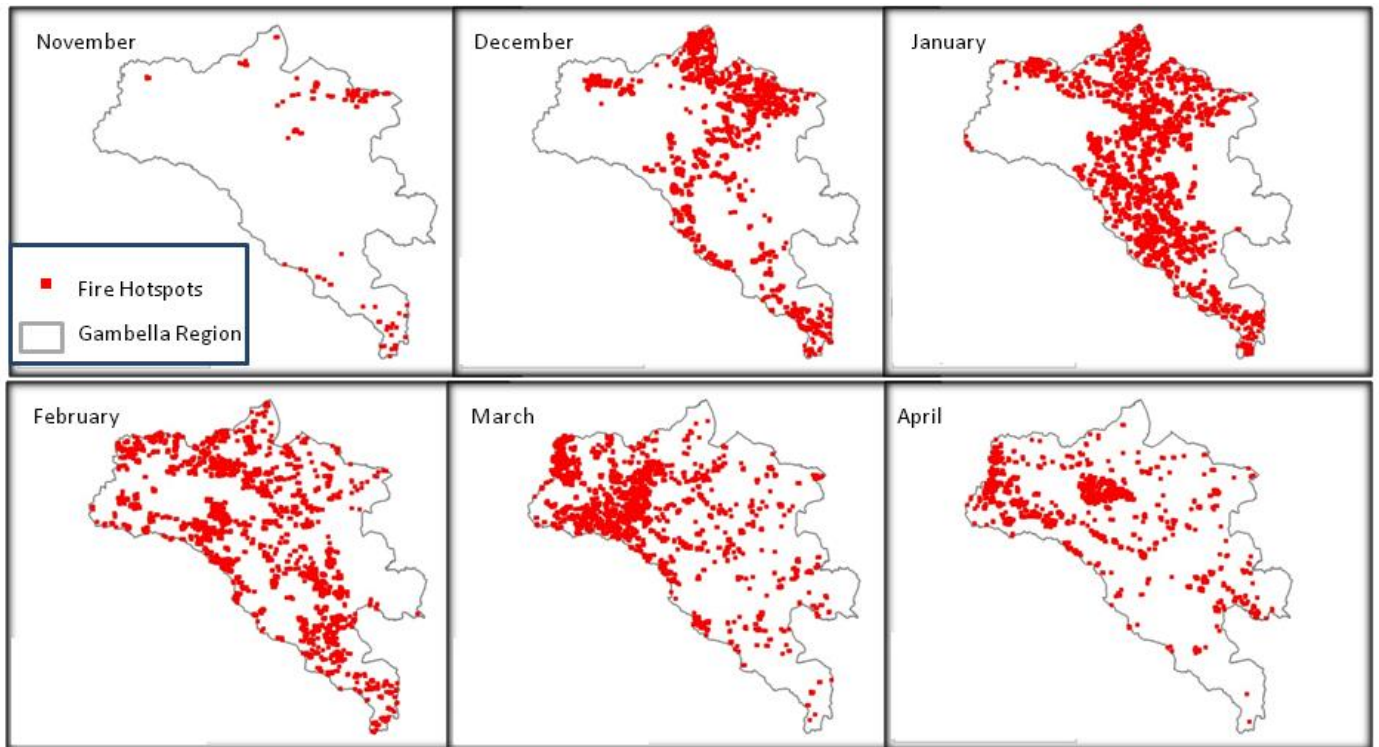


Figure 23 Fire hotspots in Gambella region from November 2013 to April 2014 (Source: MODIS)

3.6. Overlay analysis of rice and soya bean cropping calendar with roan antelope movement patterns

The location of 2050 GPS fixes received from satellite collar SAT1641, which were fitted on a roan antelope in between Saudi Star and Ruchi investment concessions were investigated. 99% of the GPS fixes were found in the investment concessions during the cropping and harvesting seasons (April – June). Except from August – November, during which they prefer foraging in the peripheries of the investment concessions. In all other months, they were found overlapping with both Ruchi and Saudi Star agricultural concessions (Fig.24).

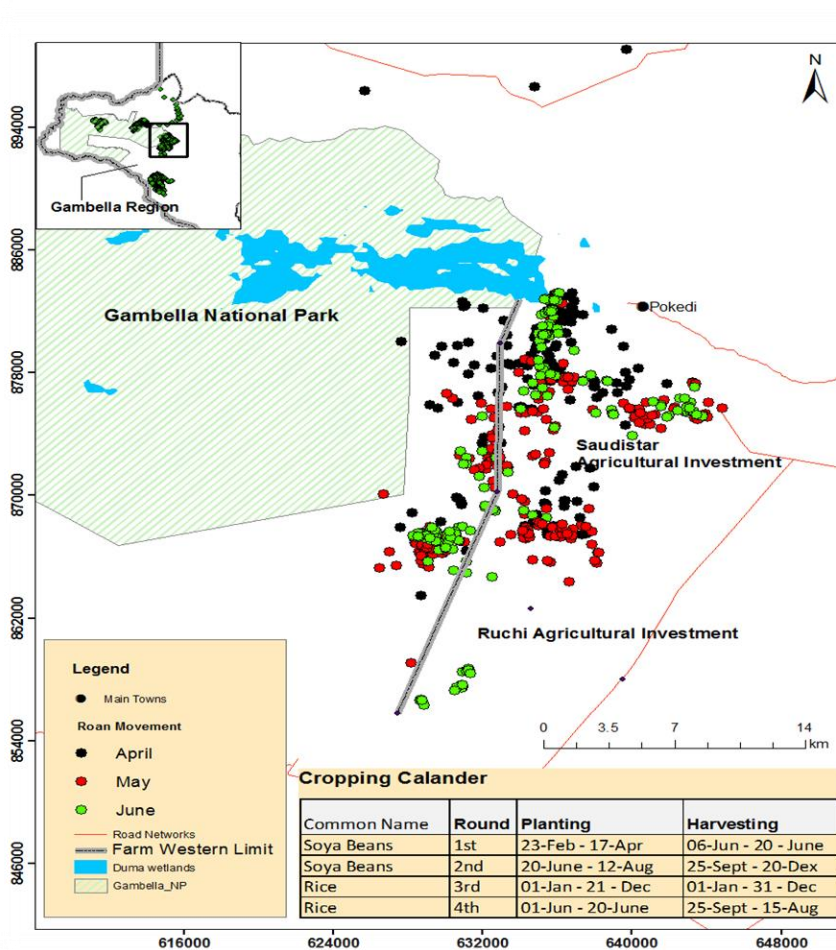


Figure 24 Collared roan (SAT1641) seasonal movement compared to rice and soybean cropping patterns

In terms of home range, all 50%, 90% and 95% Kernel density ranges were found overlapping with currently developed agricultural concessions (Fig.25). This collar roan antelope spent more than 50% of its activities outside of the Gambella National Park, at least half of which was in Saudi Star Agricultural concession.

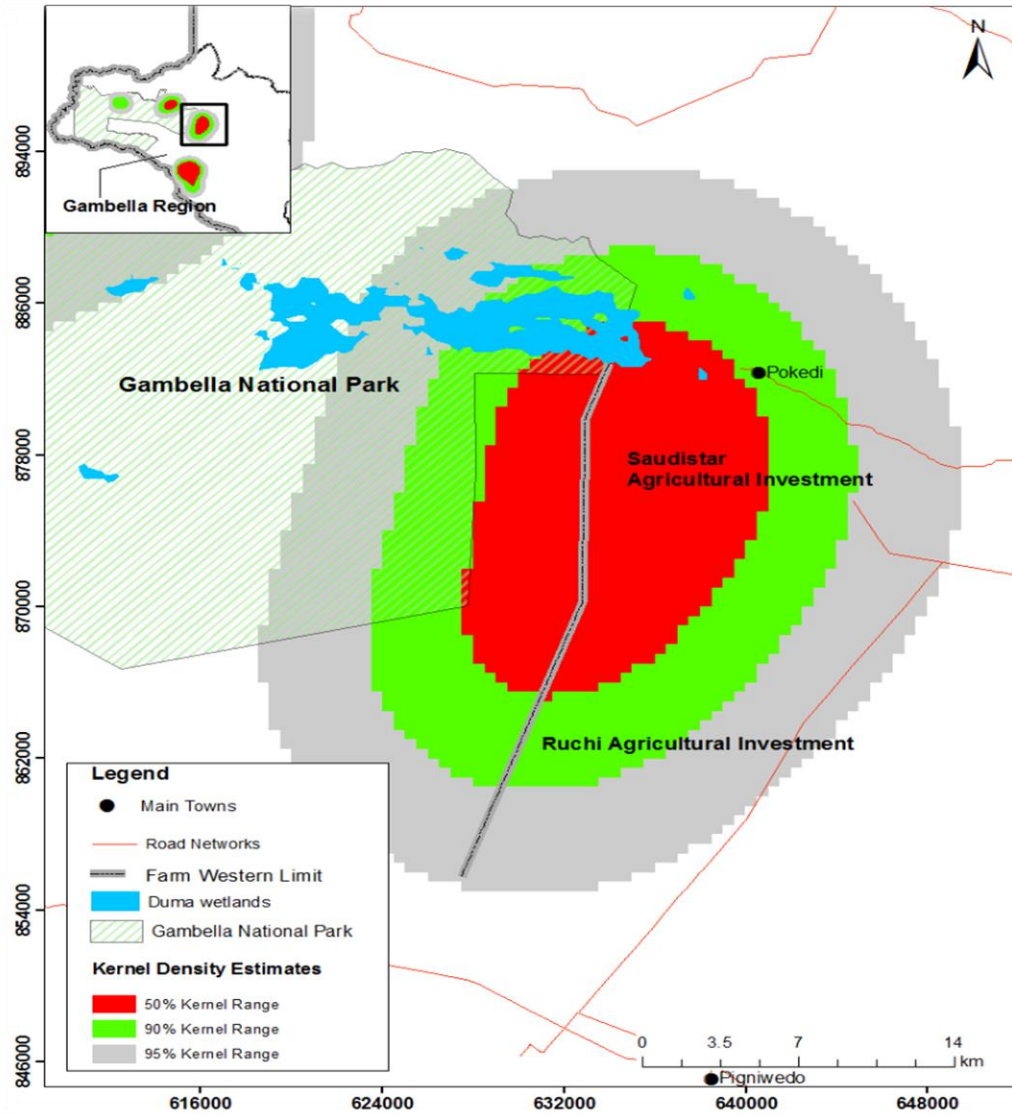


Figure 25 Collared roan (SAT1641) home range compared to rice and soya bean cropping patterns.

3.7. Opportunities for sub-regional development and transboundary conservation initiatives

Even though the Boma-Gambella landscape falls within two sovereign countries – Ethiopia and the republic of South Sudan; it is bonded with shared cultural values, ecosystem functions, prospect and challenges. The Nuer and Anywa communities live in both Ethiopia and South Sudan with intact cultural values. It has similar geological settings. It is drained by five rivers – the Baro, Gilo, Akobo, Pibor and the Baher-el Jebel Rivers. Except the last one which feeds the Sudd swamps, the first four merge to form the Sobat River. There are various permanent and non-permanent wetlands such as the Sudd, Duma, Lower Akobo, and Lower Gilo wetlands that play significant role in regulating the micro-climate and harbouring endangered species.

There is an abundance of wildlife with a phenomenal migration of Tiang and white eared kobs. However, most of key ecological and cultural attributes of the landscape fall outside the existing formal protected areas. Moreover, the landscape is shattered with several decades' long conflict. Therefore, there is a need to link landscape security, development and environmental sustainability. Transboundary connectivity conservation areas (also called peace parks) are valuable tools to harmonize conflicting interests on a landscape scale.

Having this in mind, I proposed one of the largest transboundary conservation areas (~80,000 km²), almost two and half times the size of Gambella region to be designated as a network of conservation areas. It could help both countries to meet their international commitments (e.g. the Aitchi targets) to increase the diversity and coverage of conservation areas as well as safeguards the migration routes and last strong holds of specific habitat specialist species such as the Nile lechwe, Roan antelope, Shoe billed stork and Elephants (Fig.26).

The conservation partners in South Sudan, particularly Wildlife Conservation Society, are also promoting this idea by proposing connectivity between Boma and Gambella National Parks through two corridors – the Ashumu and Omila extensions from Boma side to link with middle and lower Akobo areas of Gambella region and Gambella NP.

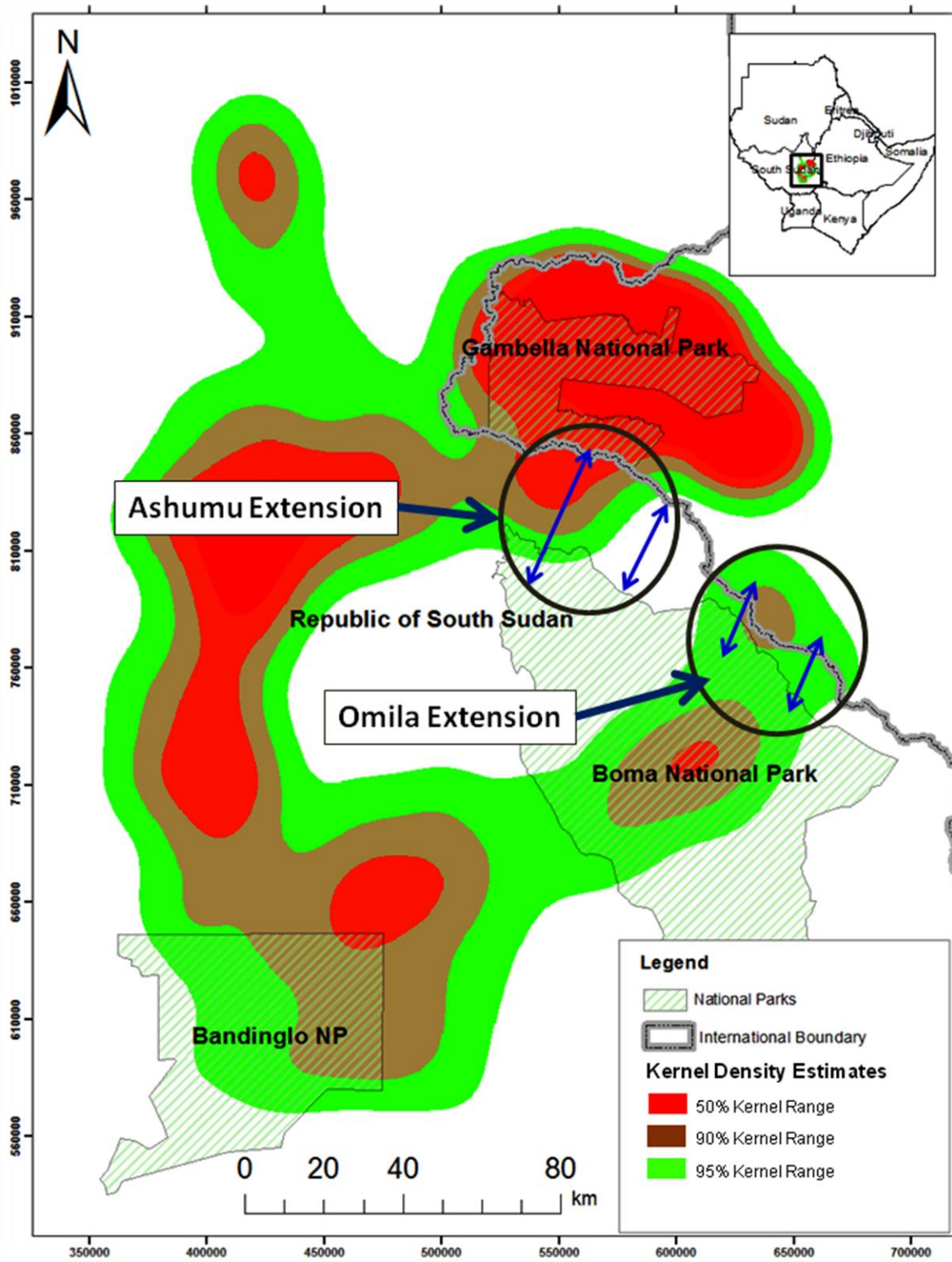


Figure 26 Transboundary connectivity corridors between Boma and Gambella landscapes

4. DISCUSSION

Earlier studies by Fryxell (1985), Malik (2014) and Malik *et al.*, (2018) on the migration routes and home range of White eared kobs restrict the phenomenon to be typical of the landscape part in the Republic of South Sudan. Most of the maps indicate northwest – southeast orientated migration routes. Supporting this narrative, Malik (2014) mentioned that kob migration ranges upto Duma wetlands east of the Boma National Park. This might be due to inadequate data about the white eared kob migration routes in Ethiopia. His analysis disregards the longest migration route that connects Gambella, Boma and Bandingilo National Parks, with projections heading up to the lower Akobo areas west of the Guraferda Mountains in Ethiopia. The Duma wetlands are some 100 km north from the northern most edge of the Boma National Park. Moreover, the Duma wetlands are not as such the parts for the core areas or the migration route of white eared kobs in Ethiopia. This might be the reason why in their recent article, Malik *et al.* (2018) estimated the contribution of Gambella landscape to be less than 1% of the overall white eared kob migration home range.

However, the recent findings have uncovered that, the White eared kob core areas in Ethiopia are stretched east-west following both banks of the Gilo river up to the confluence of Baro and Pibor-Gilo Rivers. Another cluster longitudinal orientation is connecting the Gilo area population with that of the Gambella National Park corridor projecting to Baro River just avoiding the central part of the Duma wetland to the east. For that matter, their perception of the Gambella National Park is non-existent. Because, the layer Malik *et al.*, (2018) used to map the extent of Gambella National Park has been discarded now after conservation monitoring efforts found out that the core wildlife areas are far to the west and south of the old Park extent that was on paper for decades. If the orientations of the kob migration routes as proposed by Fryxell (1985) and Malik *et al.*, (2018) were to be accept, there might be two reasons for viewing it so. There is a shift in the migration pattern and route orientation since then and the long standing civil war and conflict in South Sudan have shaped the migration route in South Sudan. I found the orientation of the migration routes to be not uniform. This hints that, the decade's long armed conflict in South Sudan, the construction of the Jongeli canal, the proliferation of oil drilling concession, settlement, livestock, and agricultural investments are altering the long foraging behaviour of the migratory kobs.

Supporting this argument, Fryxell (1985) and Fryxell and Sinclair (1988) mentioned that the construction of the Jongeli canal has divided the migration route of white eared kob and Nile lechwe.

As explained by Malik *et al.*, (2018), there is one route that starts from the unprotected area between Boma and Bandingilo and heads northwest to the Sud swamps. In my view, this is going only up to the south-eastern edge of the southern Sud swamps. Hence, this might be the same route as the one I indicated as a second (south heading) route above.

South Sudan had been in conflict almost for the past six decades. The first civil war was fought for 17 years (1955-1977). Fryxell's 1985 report came eight years after the 1st civil war ended and two years after the onset of the second civil war. The 2nd civil war was during 1983 – 2005, and the 3rd civil war from 2013 till now. Wildlife in the landscape is suffering from disturbances due to the barrier created by the Jongeli canal, oil and agricultural concessions. The vegetation state dependent migration route mapped by Fryxell (1985) should have been qualified by the deterring factors on the ground such as the ongoing conflict hotspot areas and the human settlements and their hunting grounds.

Similar timings were recorded with Malik (2014) for the onset of migration in the dry season, which is December to March to Ethiopia overlapping with peak fire season in Gambella region and then they start to return to South Sudan in early April when the rains start falling in Gambella. The challenging question here is that why do they migrate back to South Sudan when there are even better pasture and water in Gambella? Fryxell *et al.*, (1988) stated that, kobs avoid areas affected by surface flooding, and hence move to areas with short grasses than those areas with plenty of water and tall grasses. During the wet season most of low lying Gambella region is characterized by overflowing and tall elephant grasses.

Naidoo *et al.*, (2016) claims that, the Zebra migration between Namibia and Botswana to be the longest migration route in Africa. I computed that, the kob fitted with collar ID NAN59 travelled 860 km to make almost a complete looping route. This is the longest ever recorded wildlife movement distance in the African continent, compared to Plains Zebra migration between Botswana and Zambia (500 km) and Wildebeest migration between Kenya and Tanzania (400 km).

The overall orientation of the White eared kobs should be amended by aggregating the results from aerial surveys and telemetry based movement ecology analysis considered by conservation actors in

Ethiopia and South Sudan. I propose the largest transboundary network of conservation area in the continent with total size of ~ 80,000 km²; that is almost two and half times the size of Gambella region (~34,000 km²). It should include networks of different protected and conservation area diversities.

By challenging on what Malik (2014) and Malik *et al.*, (2018) have concluded, I intend to revise the migration route projections to better foster the conservation initiatives of the species in both Ethiopia and South Sudan.

My findings support the conclusions made by Tucker *et al.*, (2018) that animals that cross areas with high human footprint show a behavioural change either in terms of reduction of overall home range or even disruption of migration trends. The high population estimates during the 2015 aerial sample surveys in the Gambella part of the landscape, is an indication of the fact kobs have taken refuge in this landscape escaping the armed conflict in the Boma-Bandingilo part of the landscape.

In the long run, the cumulative impact of armed conflict, oil extraction and pipelines infrastructures (e.g. the Jongeli canal and roads), livestock grazing and agricultural investments will fragment and alter the long ranging migration behaviour of the kobs. The quest for agricultural land, oil, water and power has brought nothing but misery for both biodiversity and people of the landscape.

5. CONCLUSION AND RECOMMENDATIONS

The Boma-Gambella landscape encompasses the Gambella region of Ethiopia and the Boma and Bandingilo National Parks of Jongeli State of South Sudan. Ecosystems, cultures and challenges connect the landscape. It has been shattered by decades' long civil war and ethnic conflicts. The global quest for arable land, after the 2007/2008 international food price crisis has brought foreign direct investment in agriculture with hundreds of thousands of lands leased to investors. The discovery of oil and gas has attracted petroleum companies from China, the Middle East and the western world. More than 70% of oil and gas concessions overlap with wildlife core areas. The construction of the Jongeli canal with the controversial aim of making plenty of water available for downstream countries (Egypt and the Sudan) by diverting the White Nile River system from flowing into the Sudd swamps has blocked wildlife migration routes. Moreover, the existing protected areas were designed based of sovereign-state centric conservation approaches and most of them remained “paper parks” since their establishment. This study investigated the multitude challenges facing wildlife conservation in the landscape. This study that, GPS tagged species have responded to the disturbances caused by the ongoing armed conflict, agricultural investments and livestock encroachments. The coverage and governance gap of the existing protected areas is also accountable for the magnitude of these threats, particularly agriculture.

Most of wildlife core areas, migration routes and home ranges were found to be outside of the existing protected areas. It could be concluded that, despite all the challenges, the presence of rich biodiversity, mosaic of shared cultural and ecological attributes would bring opportunities to bring about harmonized development, peace and security.

I suggest further studies in the following areas:

- Why are migratory kobs avoiding the Pibor County while migrating back and forth during dry and wet seasons?
- What is the impact of Fullata livestock on the health and functionality of Duma wetlands in Gambella? What does this imply to the endangered Nile Lechwe population in Ethiopia?
- What would be the long-term impact of decade's' long armed conflict on migratory species?

The two counties and their respective conservation partners should join efforts to ensure the connectivity of the landscape units.

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