## The Ruma/Lambwe Valley Research Activities

Location

Our current research activities in the Lambwe valley are located within the National Youth Service (NYS) outpost at Lambwe, Ruma (00° 35' S & 34° 12' E) in Nyanza Province, Suba District, western Kenya. The altitude of the area is 1400 meters above sea level. It is situated about 10 km east of Lake Victoria in Western Kenya, southwest of Homa Bay and east of Gembe and Gwasi Hills (See map below). The terrain is mainly rolling grassland, with tracts of open woodland and thickets dominated by tree species of *Acacia*, *Rhus* and *Balanites* and a wide diversity of grass species, the dominant being *Themeda triandra*, *Panicum maximum* and *Cynodon dactylon*. The soils are largely "black cotton" clays. The park's surrounding area is settled, with a mix of small-scale cultivation and grassy pastureland. The park (formerly Lambwe Valley National Reserve) was established in 1966 but its isolation, and consequent lack of income, ensured a very slow pace of development. With its elevation into a National Park since 1983, game viewing tracks and General Park maintenance have been established however, the park still retains its natural status due to low tourism activities. Main grazing animal populations consist of roan antelope and Jackson's hartebeest, a larger and redder species than Coke's which is found in most Kenya parks, Oribi, one of the smallest of the antelope family and Rotschild giraffes.
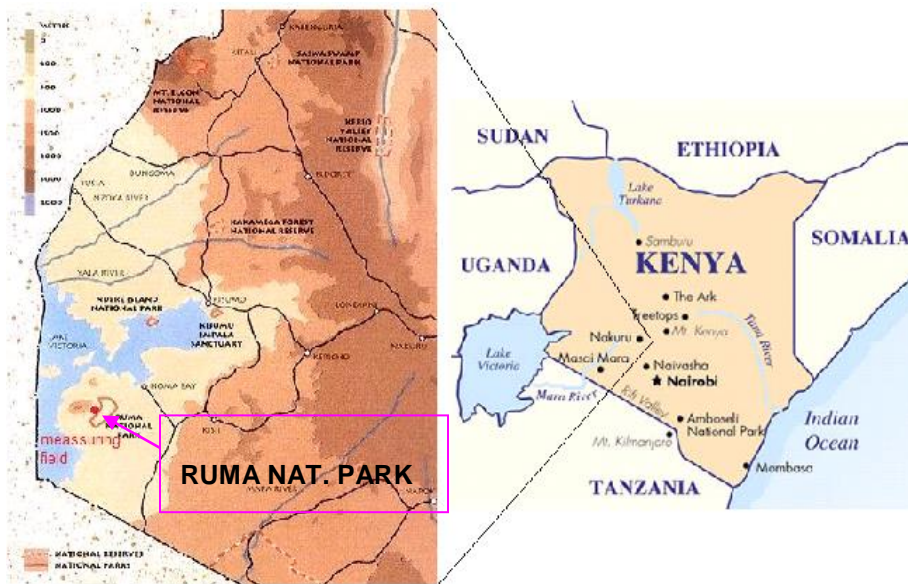
Also included within the park's enclosure but separated from the game park by a perimeter fence, is a section owned by the Kenya National Youth Services (NYS), which acts as a youth training camp. The main activities in this section include farming mainly of cereals and grazing activities by domestic animals, which has been carried out for more than a decade. The wide range of land use practices that have evolved over a significant period of time make this region a unique ecology laboratory for investigating ecosystem response to climate and land use changes.

Common land-use practices in the Lambwe valley

Climate and land use change impacts on ecosystem processes and stability in the Lambwe savanna

Climate change is exerting pressure on ecosystems in the Sub-Saharan Africa, with repercussions for the human populations dependent on them (World Bank Report-WBR, 2013; http://www.worldbank.org/en/topic/climatechange). The natural savanna ecosystems are increasingly becoming vulnerable and in the last 3-5 decades alone, they have experienced a significant decline in biomass and biodiversity (Midgley and Thuiller 2010, Higgins and Scheiter 2012) due to a combination of biophysical processes linked to climate change, especially aridity and land resource needs, associated with activities involving vegetation clearing and overgrazing (Zeng and Neelin 2000, Geist and Lambin 2005, Midgley et al. 2010). Climate projections show further decline of 30% in annual precipitation and 2-3 degrees rise in temperatures in most of the African savanna regions by the year 2100, changes that are likely to accelerate the regression process (Midgley et al. 2010, Dai 2011, Sheffield et al. 2012, Cook and Vizy 2013, Sillman et al. 2013), and savannas may shrink further to one-seventh of their current total size (Higgins and Scheiter 2012, Buitenwerf et al. 2012). Despite the apparent regression, inhabitants of most of these regions are still very strongly and directly dependant on the ecosystem and its products for their daily subsistence (Njoka et al. 2003, Fischer et al. 2005). The struggle between the regression of savanna and its quality on the one hand and the persistence of most of the ecosystem functions and interests for the people on the other hand demands that we characterize the change processes in order to unravel the driving forces of change at local scales, their effects on

vegetation dynamics (Vanacker et al. 2005) and ecosystem capacity for resilience and service delivery. While a number of reports attribute the increasing aridity in the sub-Saharan region to climate change (IPCC 2007, Fischer et al. 2005), scientific evidence is still scarce at regional to local levels.

In the Lambwe valley in south-western Kenya, forested area declined to 1% from 5%, while the area under cultivation increased from 2% to 15% in the last 4 decades. Human and livestock demographics accounted for 94% and 88%, respectively, while drought accounted for 17% of the past landcover changes and vegetation dynamics (Njoka et al. 2003). Increased intensities of cattle grazing, fire and vegetation removal has led to changes in vegetation composition, disappearance of plant species, loss of soil fertility and decline in ecosystem production. These changes must be significantly affecting the ecosystem capacity to deliver services with feedback effects on the well-being of human populations in the Lambwe valley. Since 2005, we have been conducting stepwise research activities with the aim to understand how changes in climate and land use are impacting ecosystem functioning and stability. We have been manipulating both natural and agricultural ecosystems to identify which systems are more vulnerable/resilient to climate change.
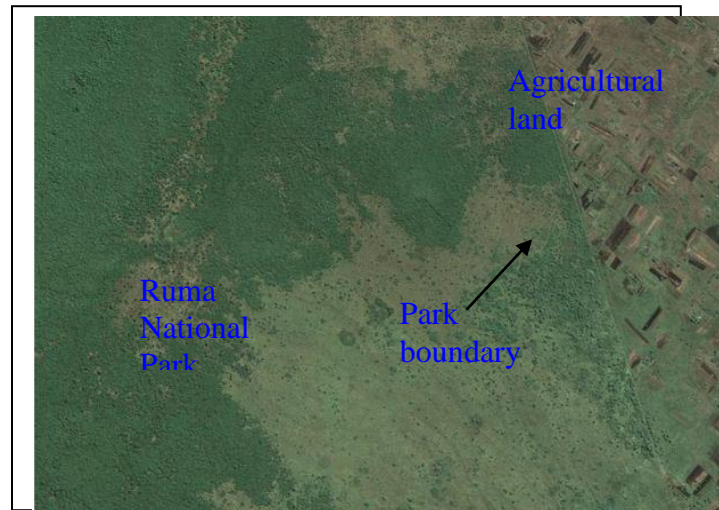
Ruma Park and its surroundings showing threats to natural ecosystems posed by farming systems and human settlements
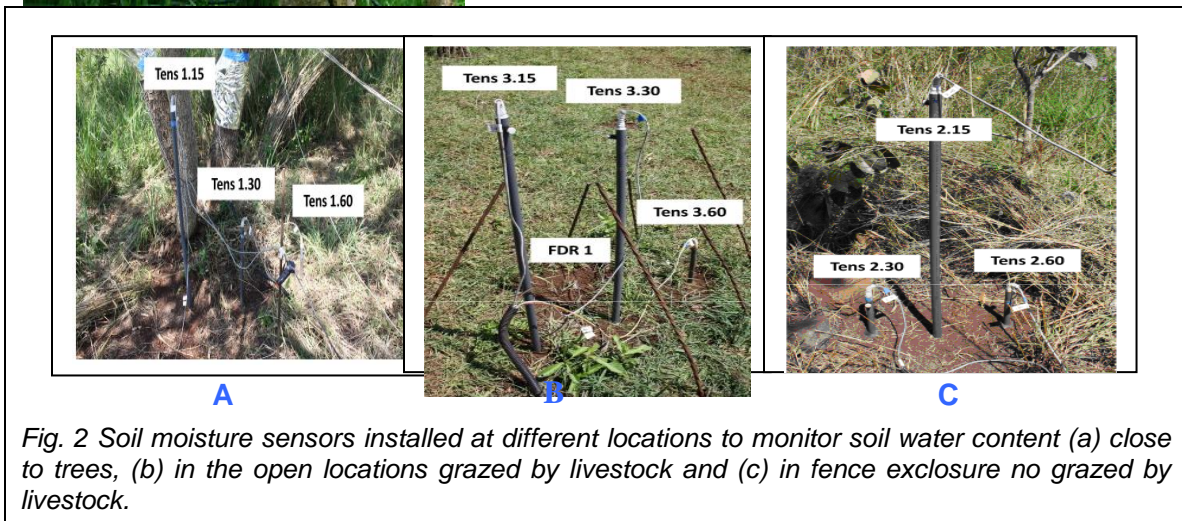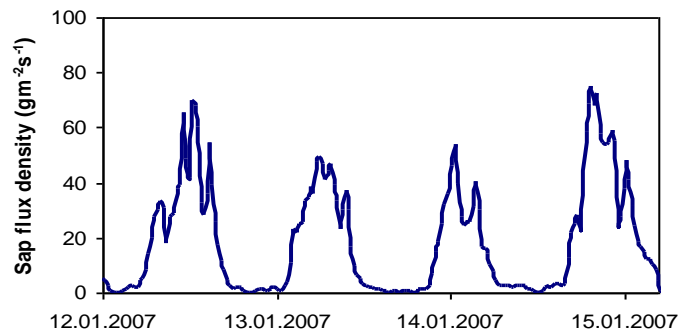
Utilization of water resources by different plant functional types in the savanna ecosystems

Funded by International foundation for sciences (IFS), this project investigated how sporadic moisture inputs in the savanna is utilised by different plant functional types (FTs), leading to storage of carbon and energy. Plant Functional Types (PFTs) were defined as sets of plants exhibiting similar responses to environmental conditions and having similar effects on the dominant ecosystem processes (Walker 1992, Noble and Gitay 1996, Dia'z and Cabido 1997). In water controlled ecosystems such as the arid and semi-arid savanna, exploitation of temporally and/ or spatially distinct zones of soil moisture by plants allows for the co-existance of different life forms (Noy-Meir 1973, Gitay and Noble 1997) as explained by the two-layer conceptual model proposed by Walter (1979). This model is supported by experiments conducted in varius similar

ecosystem set-ups (Sala et al. 1989, Walker and Noy-Meir 1982, Dodd et al. 1998). Recent studies however show that competition is a relatively frequent plant-plant interaction in the arid and semi-arid plant communities, since no clear separation is found in the root profiles of the different PFTs (Casper and Jackson 1997, Rundel et al. 2005). The vertical distribution of soil water and nutrients across the different soil layers is such that much of these resources are likely to be in the top 50-60 cm of the soil, implying that virtually all the PFTs including annuals and perennials are "drinking from the same cup" (Reynolds et al. 2000, 2004 or by maintaining balanced competition with each other (Higgins et al 2000). Dissimilarity in resource use patterns among functional groups would imply functional diversity characterized by morphological and physiological differences (Baldocchi et al. 2004, Pokorny et al 2005, Lavorel et al. 2007). Thus, different PFTs are expected to play different roles in terms of matter and energy processes in the ecosystem and provide a framework for predicting ecosystem response to perturbations both at local and at global scales. Shifts in composition of functional groups resulting from ecosystem perturbations alter soil nutrient concentrations, water cycling and community production (Hooper 1998, Kirk et al 2007). Identification of the overall ecosystem responses to perturbations is an essential step in global change research initiatives. This can be achieved through examining both morphological and physiological features and exploring the role of the main plant traits in ecosystem function, particularly in relation to water, mineral and carbon exchange. Understanding how soil water resources is being utilized by the different PFTs and the changes that may occur as a result of ecosystem disturbances is crucial in predicting the fate of savanna ecosystems in the changing climate scenario (Climate Change 2001, Reynolds et al. 2004).

Methodology

The main measurement technique employed here was sapflow methodology. The heat dissipation technique of Granier [1987] allowed us to constantly monitor sapflow in different tree types. Also soil moisture at the rhizosphere of different trees was closely monitored using TDR sensors.

Fig. 2 Soil moisture sensors installed at different locations to monitor soil water content (a) close to trees, (b) in the open locations grazed by livestock and (c) in fence exclosure no grazed by livestock.

Interactive Influence of Land-use and Rainfall on the Structure and Function of The Herbaceous Layer Community of a Moist Tropical Savanna

Tropical savannas are vulnerable and may be undergoing changes in their structure and function as a result of shifts in climate and land use that could impact their capacity to deliver ecosystem services as well as feedback into regional climate. Our objective is to examine how changes in precipitation regime impact the structure and function of the herbaceous layer community of a moist savanna ecosystem subjected to different land uses. Using rainout shelters, precipitation will be manipulated so as to attain 50% reduction and 50% increase of the ambient rainfall. Land use will comprise grazing and shifting cultivation, resulting in a factorial design comprising 3 levels of land uses and 3 levels of rainfall regimes. Measurements on species composition, soil characteristics, nitrogen distribution, ecosystem CO_2 exchange and carbon partitioning and storage will be conducted for a period of 2.5 years at Ruma National Park, Kenya. Ecosystem CO_2 fluxes will be monitored using chambers and stable ^{13}C isotope.

Methodology

Stratified measurements are conducted to identify the impact of land use and rain exclusion on ecosystem processes, mainly biomass production, soil characteristics, species composition of the herbaceous vegetation and ecosystem CO_2 exchange. The first work package (WP1) monitors aboveground CO_2 fluxes, plant species composition and biomass development in the herbaceous layer vegetation in 3 different land use plots/ rainfall regimes. The second work package (WP2) involves monitoring below ground processes, root biomass development, root length and root diameter increases, in addition to soil respiration in the 3 land use types/rainfall regimes. A third work package (WP3) involves intensive measurements of soil moisture, soil nitrogen (N) and soil carbon (C) concentrations in the different land use plots with varying rainfall intensities.
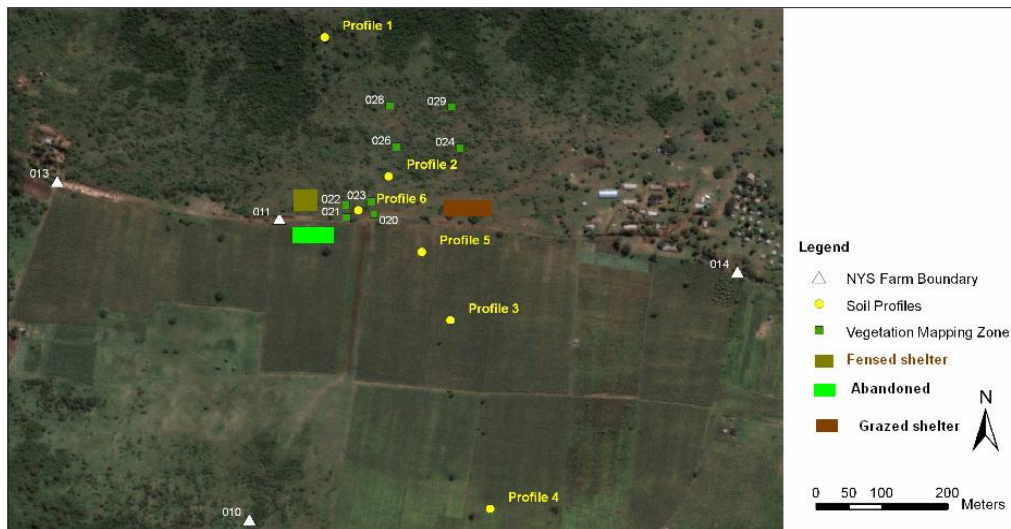
Layout of the research field site at Ruma

WP4 involves monitoring of water use by trees in the grazed and fenced plots. Water use is monitored through sap flow measurements on the dominant trees on the plot. Alongside these measurements, we also monitor the microclimate of the study site. Parameters being monitored include air temperature, air humidity, rainfall, global radiation, wind velocity and direction on two weather stations erected on the site. Our goal is to integrate data from these different approaches in order to gain knowledge of how this ecosystem functions.
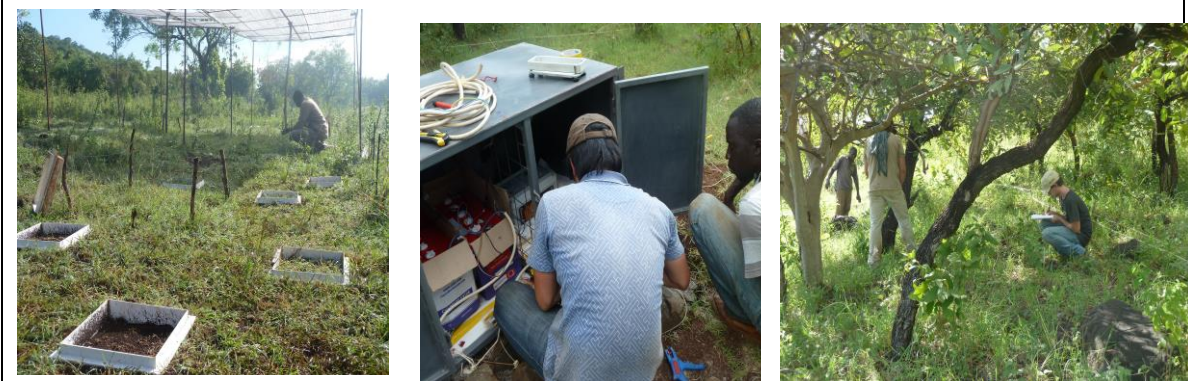
Fig. 3 Showing (a) biomass harvesting under one of the rainout shelters constructed on the grazed plot. In the foreground are soil frames on which soil CO_2 flux chambers are placed to assess soil respiration. (b) Shows sapflow measurements while (c) shows vegetation mapping of the herbaceous layer.

Interactive Influence of Livestock Grazing and Precipitation on Tree Species Productivity and Distribution in the Savanna Ecosystem in Lambwe valley, Western Kenya

The Africa savannas are increasingly becoming vulnerable and have experienced a significant decline in vegetation biomass and biodiversity in the last 3-5 decades. This is despite the fact that its inhabitants are still strongly dependant on the ecosystem products for their daily subsistence. Changes in climate (increasing aridity) and land use maybe responsible, however, there are no direct scientific evidences linking them to the savanna regression. Characterization of the change processes, the driving forces of change, their effects on vegetation dynamics and ecosystem capacity for resilience and service delivery are urgently needed in order to adapt to the environmental changes and stop the regression process. In Lambwe valley in western Kenya, land use change associated with intensive livestock grazing and declining precipitation amounts have been blamed for the ongoing tree dieback and species loss. To identify the influence of precipitation and grazing on the functioning of tree species in this savanna, field experiments will be conducted in (i) a preserved natural savanna ecosystem inside Ruma national park, grazed only by wildlife and (ii) a modified savanna outside the national park grazed by livestock. Measurements will also be performed on seedlings of the same species under controlled greenhouse conditions for the purpose of identifying mechanisms of water stress tolerance or tree dieback. Controlled, severe water stress will also be inflicted on the seedlings to identify adjustments to water stress that develop during pre-conditioning. Our study hypothesis is that tree mortalities in the savanna are due to declining precipitation amounts and intensive grazing causing inter-annual cumulative soil moisture deficits, and thereby leading to plant water deficits, cavitation of water conducting vessels, stomatal closure, carbohydrate deficits and tree die-back. The main study objectives are (1) to quantify changes in soil characteristics arising from livestock grazing and reduced precipitation, (2) to characterize responses of tree species to

soil moisture changes, both under field and greenhouse conditions, (3) to identify superior qualities in the juvenile tissues arising during early exposure to water stress (pre-conditioning) that can enable them survive drought. The experiments are planned for a period of 2.5 years. Our goals are (i) to identify causes of tree die back and species loss and mechanisms of adaptation and survival in the savanna and (ii) identify approaches that could make trees more adapted to drought stress, especially at their juvenile and more vulnerable stages.

Assessing Shifts in Plant Community Composition and Overall Ecosystem Structure and Function in the Emerging Climate Scenarios in the Savanna

Co-existence among different functional groups in the savanna is by occupying different niches due to functional diversity resulting from morphological and physiological differences. Composition of functional groups is however, likely to shift as a result ecosystem perturbations, altering soil nutrient concentrations, water cycling and plant function. The study was designed to assess ecosystem response to declining precipitation amounts in the savanna attained through rain exclusion using rain gutters constructed on the experimental plots. Three precipitation levels were established by excluding 0% (Control treatment), 10% and 30% of rain water. Monthly assessments of soil moisture, nutrient N, species composition, net ecosystem CO_2 exchange (NEE), ecosystem respiration (Reco) and biomass accumulation were conducted. In addition, we included components to the project that were not planned but became critical to allow for better understanding interpretation of our results. Since most of the rain exclusion experiments were carried out within fence enclosures, we discovered that this may not be a true representation of a natural savanna. Exposing the rain exclusion experiments however, was not possible since the gutters could be destroyed by grazing animals. We therefore, conducted parallel experiments in the open grazed areas, alongside our fence enclosure to monitor seasonal trends in a natural savanna. We have also examined heterogeneity in structure and function that may arise due to farming, presence of trees as well as termite mounds.

This project delivered basic information on the responses of moist savanna, acting as a framework for planning further research activities to explore more into areas that could not be covered within the context of its mandate. It was the first time such kind of a study was being done in this region. The results have generated a lot of interest to further these research activities. Being a national park, our publications provide a marketing opportunity for the Kenyan wildlife resources and we hope that many researchers will make a follow-up of our current results in the future.

Experimental design

Rain exclusion experiments were randomized block design consisting of three levels (ppt= 100, 90 and 70 %) of soil water treatments with three replications. These were effected by the use of gutters constructed on the study plot (see diagram 3). Each treatment block measured 10 by 15 m separated by 5 m strip between them. The gutters were constructed from transparent plastic sheets (>95 % light penetration) raised at about 0.2 m above the ground. The amount of rain allowed was determined by the number of gutters, which was a fraction of ground cover as determined by the % precipitation required.

*Rain gutters constructed on the plots to exclude rain water*

Measurements

Microclimate

Weather parameters continuously monitored include air temperature, air humidity both in the shade and open locations using Fischer sensor, photosynthetic active radiation (PAR) using LI-190, LI-COR, USA and light intensity and air temperature above the ground surface using HOBO. Soil moisture in the treatment plots is being monitored at 30 cm depth with ECHO probes EC-50, Decagon, USA.

Ecosystem CO_2 exchange

Ecosystem gas exchange is measured monthly using self-developed ecosystem monitoring unit Temperature and light conditions within and outside the chambers are continuously monitored during measurements. Gas exchange of the ecosystem is obtained by differential measurements of CO_2 uptake (NEE, transparent chamber) and release (Reco, darkened chamber) and gas analysis is done using LI-COR 820, portable gas exchange analyzer connected to the chamber through tubes. The entire system is a closed chamber system. Pressure equilibration in the chamber is achieved through an opening at the top of the chamber, which is closed as soon as measurements begin.
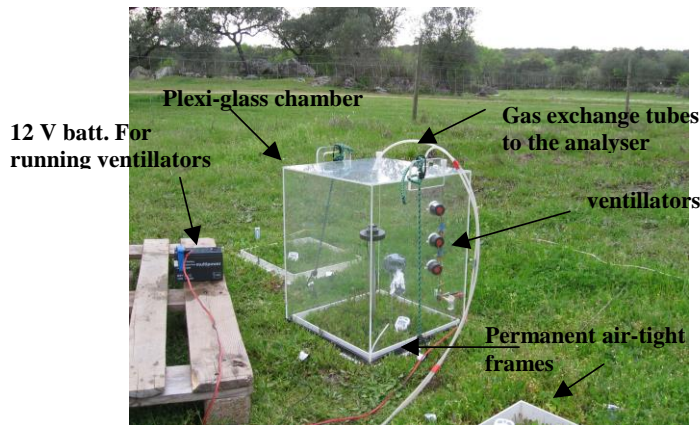
Ecosystem CO$_2$ measurement system employed to asses CO$_2$ gas fluxes in the herbaceous vegetation

Measurement of ecosystem CO$_2$ exchange, biomass productivity and species composition in the herbaceous vegetation in Lambwe

Above- and belowground biomass sampling

Above and below ground biomass are obtained every two weeks from the same frames (38.9 cm by 38.9 cm) after gas exchange measurements. At every sampling, a total of 3 samples are obtained from each block. Aboveground biomass is clipped to ground level and transported in polythene bags and cool boxes to the lab where the plants are separated and identified and the dead biomass sorted. Fresh leaves are separated and leaf area, leaf area index and specific leaf weight determined. All the samples are oven dried to a constant weight before determining the dry weight. Below ground biomass is estimated by extracting soil cores down to 20 cm (3 cm diameter) from the 18 plots for aboveground biomass sampling. The soil column will be split into layers of 0 - 5, 5 – 10 and 10 - 20 cm depths. Fresh weight of the layers are immediately determined in the field. The roots and attached rhizomes are removed from each soil layer within 48 hours and washed. The washed belowground components will be oven-dried at 90°C for 48

hours and weighed to determine root biomass profiles. Gravimetric moisture content is determined for all layers by drying fresh-weighed soil samples at 100°C until a constant weight is obtained. This is then be subtracted from the original soil weight, minus root biomass to determine soil water content.

Carbon Partitioning

The partitioning of carbon to different Carbon pools within the ecosystem is being monitored through the use of 13C isotope. Enrichment is conducted on enclosed vegetation by feeding labeled carbon generated after reacting $(NaH)_2{}^{13}CO_3$ with H_2SO_4 into the enclosed transparent chamber described in 2.3.2. During the enrichment, the CO_2 levels within the enclosed chamber are monitored using LI-820 gas analyzer. Samples which include shoot, root and soil are obtained soon after enrichment and also subsequently after enrichment for a period of one month. Between 0.2-0.5 g of $NaH^{13}CO_3$ is reacted with excess acid. The Samples are then analyzed days of Root, Leaf and stem portions of harvested plants are analyzed for nitro at the isotopic lab, University of Bayreuth.

C/N determination

On a monthly basis, soil and plant samples are obtained from the different plots for analysis. Soil samples are extracted using increment to cores to a depth of 30 cm. Analysis of the samples are done at the plant ecology department, University of Bayreuth.

Achievements

We have now established a strong working relationship between UBT, Maseno University and the National Youth Service at Lambwe. Since 2013, we have started working together with the Kenya Wildlife Services at Ruma.

Staff of the National Youth Service at Ruma and students from UBT and Maseno University

Several students have been able to earn their respective degrees through the project at Ruma and some are at different stages of their professions. We have also managed to publish a series of papers.

Doctoral theses

1. **Daniel Osieko (2011).** Interactive Influence of Land-use and Rainfall on The Structure and Function of The Herbaceous Layer Community of a Moist Tropical Savanna. Ecology Department, University of Bayreuth, Germany.

2. **Thomas Leipold (2011).** Controls on Ecosystem Water Use and Carbon Gain at Mt. Kilimanjaro – Differentiation along climate gradients and with land use from the savanna to the alpine zone. Plant Ecology Department, University of Bayreuth, Germany.

Master theses

1. **Joseph Ondier Otieno (2012).** Influence of land use on soil respiration and root growth in the herbaceous component of a moist Kenyan savanna. Department of Botany, Maseno University, Kenya.

Completed theses:

Doctoral theses

1. George O. K'Otuto (2010). Effects of agro-ecosystems on the carbon dioxide exchange and carbon storage in the grass component of a moist savannah ecosystem. School of Agriculture and Food Security, Maseno University, Kenya.

Master theses

1. **Melanie Hauer** (2011). Crown heterogeneity of the African arid savanna trees and how it influences recovery after drought. Plant Ecology Department, University of Bayreuth.

2. **Bálint Jákli** (2011). Influence of soil moisture on the ecosystem CO_2 exchange of the herbaceous vegetation of an African arid savanna. Plant Ecology Department, University of Bayreuth.

3. **John N. Maina** (2009). Effects of ungulate herbivory and trees on ecosystem processes in wet tropical savanna. Maseno University, Kenya.

Bachelor theses

1. **Markus Holzner** (2013). Der Vegetationswandel um den Victoriasee innerhalb des letzten Jahrhunderts: Fallstudie feur die Region Lambwe Tal, Landkreis Homabay, Kenia.

2. **Patrik Schröttle** (2011). Einfluss von Termiten auf Wasser- und Nährstoffverfügbarkeit im Boden rund um ihre Nester und die Auswirkungen auf die mliegende Vegetation in der Savanne. Bachelor thesis, Plant Ecology Department, University of Bayreuth.

3. **Bálint Jákli** (2011).Einfluss von *Acacia* auf Wasserverfügbarkeit, CO_2-Flüsse und Biomasseproduktion in einer ostafrikanischen Savanne während Trockenperioden. Plant Ecology Department, University of Bayreuth.

4. **Frank Breiner** (2008). CO_2 Austausch und Kohlenstoffverteilung in der tropischen Savannenlandschaft in Abhängigkeit von Beweidung und Wasserverfügbarkeit. BSc. thesis, University of Bayreuth, Germany

Publications in reviewed journals

1. Schweiger A. **Otieno D.O**., Reinerking B. and Tenhunen J. (2013). Micro-climate amelioration of the afro-alpine cushion-forming shrub Helichrysum citrispinum facilitates primary production of understory plants (submitted), Alpine Botany.

2. **Otieno D.O**., Li Y., Hussain Z.M., Lindner S., K'Otuto G.O. and Tenhunen J. (2013). Temperature and Precipitation Switch Grasslands between Net Carbon Sinks and Sources: evidence from chamber and Eddy measurements (Agr. Ecosyst. Environ).

3. K'Otuto G.O., **Dennis O. Otieno**, John C. Onyango & Harun.O. Ogindo 2013. Seasonal dynamics of carbon dioxide exchange of the herbaceous layer of a moist Kenyan savannah (In Press). *Applied Ecology and Env. Research*. 11.

4. K'Otuto G.O., **D.O. Otieno**, B. Seo, J.C. Onyango and H.O. Ogindo 2013. Carbon dioxide exchange and biomass productivity of the herbaceous layer of a managed tropical humid savanna ecosystem in western Kenya. J Plant Ecol. 6:286-297.

5. Maina J.N., Wang Q., **Otieno D.**, Oula D., Mupenzi J.P., Onyango J.C. 2012. Interactive effects of livestock and trees on nutrients and herbaceous layer production in a humid Kenyan savanna. *East African Journal of Science and Technology*, 2012; 1(1):9- 26.

6. **Otieno D.O.**, G. K'Otuto, B. Jákli, P. Schröttle, J.N. Maina, E. Jung & J.C. Onyango 2011. Spatial Heterogeneity in Structure and Function of a Moist Savanna in Ruma National Park, Kenya. *Plant Ecol*. 212:769–783.

7. **Otieno Dennis**, K'Otuto George Ohuma, Maina John Nyongesa, Kuzyakov Yakov & Onyango John Collins 2010. Responses of ecosystem CO_2 fluxes to soil moisture fluctuations in a moist Kenyan Savanna. *J. Trop. Ecol.* 26:605-618.