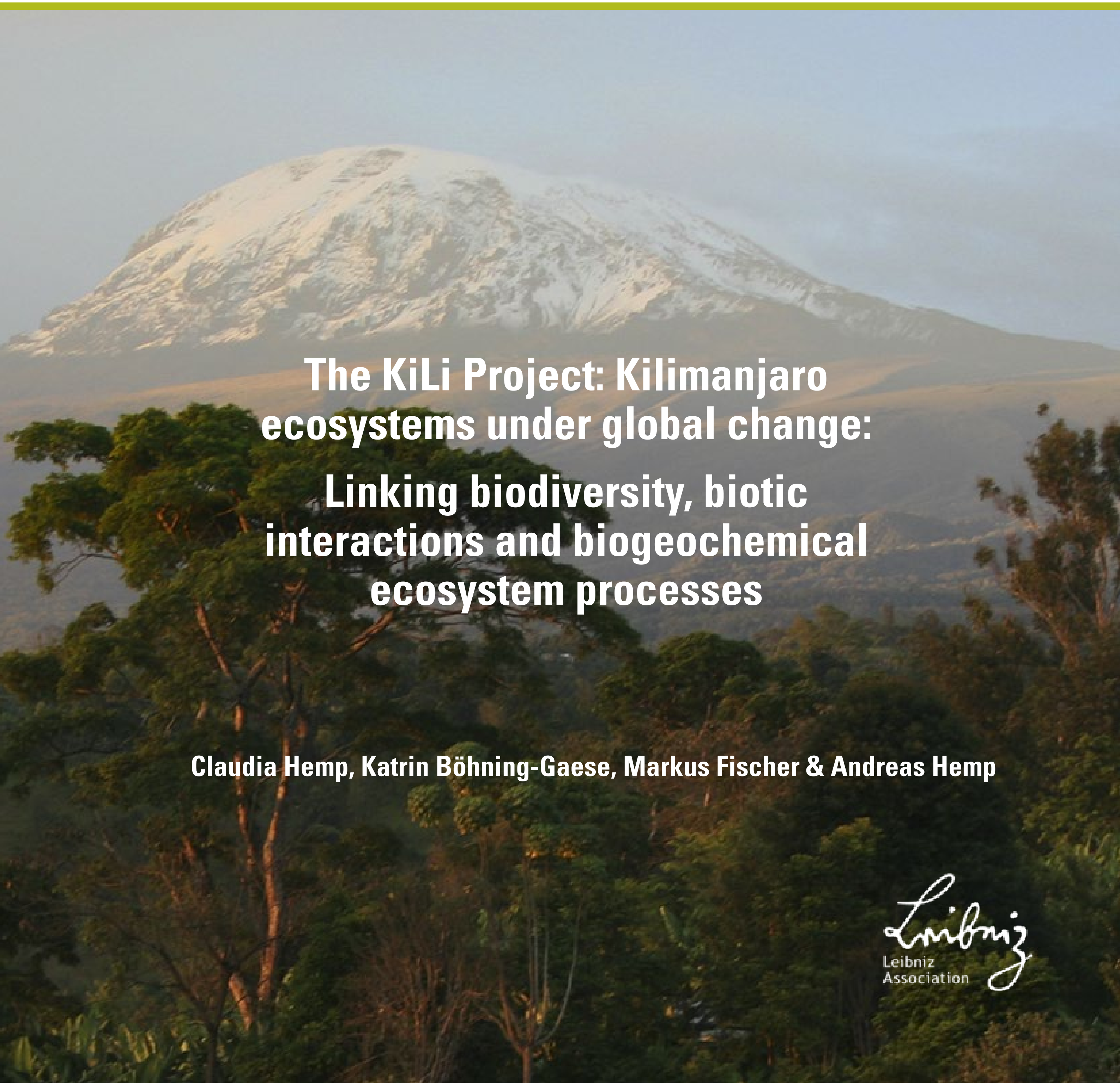
SENCKENBERG

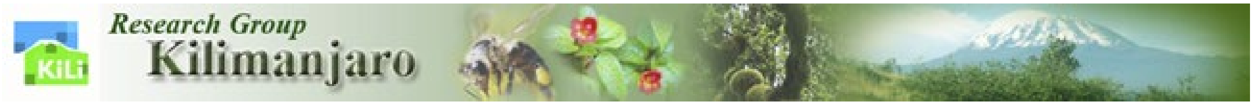


The KiLi Project: Kilimanjaro ecosystems under global change:

Linking biodiversity, biotic interactions and biogeochemical ecosystem processes

Claudia Hemp, Katrin Böhning-Gaese, Markus Fischer & Andreas Hemp

Leibniz Association


KiLi
Research Group
Kilimanjaro

Imprint

Publisher
Senckenberg Gesellschaft für Naturforschung,
Senckenberganlage 25, 60325 Frankfurt/Main, Germany

Authors
Claudia Hemp & Katrin Böhning-Gaese, Senckenberg Biodiversity and Climate Research Centre (SBiK-F),
Senckenberganlage 25, 60325 Frankfurt (Main), Germany
Andreas Hemp, University of Bayreuth, Plant Systematics, Universitätsstr. 30, 95447 Bayreuth, Germany
Markus Fischer, University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Layout and Image Processing
Claudia Hemp
Petra Schwarzmann, www.ps-designwerkstatt.de

Printing and binding
bis500druck, Klicks GmbH, Ziegelhüttenweg 4, 98693 Ilmenau, Germany

ISBN 978-3-929907-96-4

www.senckenberg.de

Printed in Germany

This project was funded by the German Research Foundation (DFG)

DFG Deutsche Forschungsgemeinschaft

The KiLi Project: Kilimanjaro ecosystems under global change: Linking biodiversity, biotic interactions and biogeochemical ecosystem processes

Claudia Hemp, Katrin Böhning-Gaese, Markus Fischer & Andreas Hemp

Senckenberg Gesellschaft für Naturforschung

CONTENTS

A Word from Tanzania Wildlife Research Institute

by Dr. Victor Alexander Kakengi,
Principal Research Officer

The DFG funded KiLi Project is among the few long-term projects registered with TAWIRI, however with a unique frame-work. It is a research program with a good number of research projects, all aiming at studying impacts and land-use change on a range of organisms and on ecosystem processes/functions along the gradient of Mt. Kilimanjaro. Generally, it has contributed significantly to the knowledge about continuous interaction between biotic and abiotic factors and human influence that aggravate the impact of climate change probably leading to noticeable abrupt changes on the highest mountain in Africa. The KiLi research program contains research projects that have a number of thrilling research questions. To answer these research questions, the project uses a multi-disciplinary team with Principal Investigators (PIs) from various European and Tanzanian universities and institutes. Under the supervision of these PIs, a total of 60 Master and PhD enrolled students have made enormous contributions resulting in more than 100 scientific articles in a number of reputable journals. Apart from these publications, each study generated information that has conservation implications. Therefore, we urge the management of Kilimanjaro National Park to translate the obtained research findings and put into use so as to improve conservation of Mt Kilimanjaro. Apart from generated scientific information the KiLi research project has made a noticeable and commendable contribution to capacity building where a total of 16 Tanzanian PhD students from various government institutions were enrolled between 2010 – 2018. Most of the enrolled students have completed whereas few of them are about to complete their studies. We thank the KiLi Project for the enormous capacity building made to Tanzanian Institutions, and we believe that the knowledge accrued from their studies will be used to improve their working efficiency which will eventually contribute to development of their institutions, and the country at large. On top of the above achievements of the KiLi project, the recent and credible discovery of Africa's tallest indigenous tree *Entandrophragma excelsum* measuring a whopping 81.5 metres discovered in a remote valley on the continent's highest mountain, Kilimanjaro, was an exciting attribute that will have tourism implications.

We believe that this finding will be used by KINAPA to attract more tourists who will not only come to climb the highest mountain in Africa but also to see the tallest tree on the continent and probably the fifth tallest in the world. The finding will hopefully also ensure that the last patches of indigenous submontane forests on Kilimanjaro will be safeguarded now. On behalf of the Tanzania Wildlife Research Institute, I highly appreciate the contribution of the KiLi Project to science which if translated and used properly will improve conservation of Kilimanjaro National Park. We acknowledge the funding by the German Government through the DFG and emphasize that there has been a value for money when relating the generated useful scientific information that has been made in the short span of 8 years. We urge the German Government to add more phases for the project which will contribute even more to the scientific knowledge and improve further conservation of Kilimanjaro National Park and of Tanzania as a country.

Preface

Before the KiLi Project…

by Claudia & Andreas Hemp

In early 1989 Prof C. Winter asked Andreas Hemp to join his team and work with him on a dictionary on the Chagga language. His task would be to scientifically identify plant species and find out about their common names in the Chagga and Swahili languages. Thus, in October 1989 Prof Winter dropped Andreas Hemp and his fiancee Claudia at the old missionary house of Old Moshi, the former sisters house of the station of the famous missionary and ethnologist Bruno Gutmann to stay for 7 months. After two successive DFG funded ethnobotanical projects a project on ethnozoology conducted by Claudia Hemp followed. The beauty and biological richness of Kilimanjaro and Tanzania on the whole and the kind people induced Andreas and Claudia Hemp to apply for more – this time – first botanical and later also zoological focused research projects. The first two children, Judith in 1993 and Julian in 1995, born to them were partly educated in Tanzania. Also their third child, Kerstin born in 2003, stayed most of the time during her early childhood in Tanzania while their parents worked scientifically first on Mt Kilimanjaro, later expanding their focus to further parts of Tanzania and Kenya. During this time a profound data base on the vegetation and the Orthoptera fauna of Tanzania and Kenya was obtained and finally served as a foundation to think about a larger, interdisciplinary oriented project.

First steps of the KiLi Project…

Fortunately in 2007 Andreas met Markus Fischer while getting involved in eastern Germany with the newly founded Biodiversity Exploratories. Andreas was responsible for choosing research plots and managing the group at Schorfheide-Chorin for more than 3 successive years. The research design of the Bioexploratories then induced both Markus Fischer and Andreas Hemp to think about a similar research group on Mt Kilimanjaro. In 2007 a first meeting in Bayreuth took place to discuss topics and contributing scientists of the planned research unit. Scientists present at this time later became the first team to start research in the framework of the KiLi Project.
All future participants and reviewers from the **German Research Foundation** participated at an evaluation meeting in Moshi in January 2008 (Figs. 1–3). Very soon it became clear that Kilimanjaro together with the profound data base available, the good connections to Tanzanian authorities and scientific institutions and an excellent infrastructure in form of two scientific stations would almost guarantee the success of such an interdisciplinary research project. Elected speaker of phases 1 & 2 was Ingolf Steffan-Dewenter while in 2016 Katrin Böhning-Gaese was appointed speaker of the third phase of the project.

Figs 1–3. Project leaders and representatives of the DFG in Old Moshi, Kidia (left), at the scientific station Nkweseko (middle) and during an excursion through the forest belt along the Machame Route (right) in January 2008.

Summary – Results of the KiLi Project 2010–2018

by Katrin Böhning-Gaese, speaker phase 3

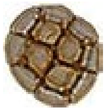
General questions and infrastructure

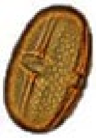
- This brochure presents some of the most important results of the **Kilimanjaro Project**, a Research Unit funded by the German Research foundation, complemented by results from almost 30 years of research on Mt Kilimanjaro by **Andreas and Claudia Hemp**. The core objective of the Kilimanjaro project was to understand effects of climate and land-use change on biodiversity, biotic interactions, and biogeochemical ecosystem processes.
- The study has been funded for 8 years. **Core research infrastructures** are the establishment of 65 plots (among them 13 focal plots) in 13 representative habitat types, covering the whole elevational and land-use gradient on the southern slope of Mt Kilimanjaro as well as two experimental gardens. On the plots, **researchers measured** a broad range of abiotic and biotic parameters, ranging from temperature, precipitation and biogeochemical processes to the diversity of multiple taxonomic groups, their traits and biotic interactions.

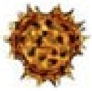
In the following, results of the research efforts are presented:

Maps and atlas data:

- Over 1600 vegetation plots were used with intensive land surveys to prepare **a first detailed vegetation map of Mt Kilimanjaro**. This map was taken to develop a high-quality physiographic map as a base for ecotourism, nature conservation and land planning at a scale of 1:100,000 for the entire Kilimanjaro massif. Besides a highly accurate relief representation, the map shows the complete infrastructure of the National Park as well as the current vegetation distribution and land-use.
- In addition, a unique **pollen and spore atlas** has been compiled, covering the whole East African region. In this atlas, we provide an overview on the range of most important pollen and spore types found in the last glacial and Holocene environmental archives in studies on and around Mt Kilimanjaro. This atlas contributes to the reconstruction of the vegetation history of Mt Kilimanjaro and other East African regions.







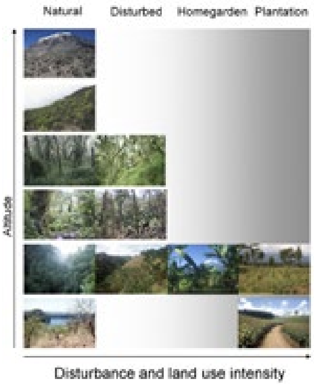
First preparatory meeting of the KiLi Project in January 2008. From left to right: Christian Lambrechts, UNEP, Nairobi, Dr Andreas Huth (UFZ), Dr Sonja Ihle (DFG), Prof John Tenhunen (Univ. Bayreuth), Prof Hermann Behling (Univ. Göttingen), Dr Andreas Hemp (Univ. Bayreuth) with his daughter Kerstin, Prof Michael Kleyer (Univ. Ulm), Dr Ralph Kiese (KIT), Prof Yakov Kuzyakov (Univ. Göttingen), Prof Bernd Huwe (Univ. Bayreuth), Prof Michael Schmitt (Museum Koenig Bonn), Prof Ingolf Steffan-Dewenter (Univ. Würzburg), Prof Katrin Böhning-Gaese (BiK-Frankfurt), Prof Markus Fischer (Univ. Bern) and Prof Elisabeth Kalko (Univ. Ulm).

Maswali ya Jumla na Miudo mbinu ya Mradi wa KiLi

translated by Victor Kakengi

– Kipeperushi hiki kinawasilisha muhtasari wa matokeo muhimu ya mradi wa KiLi (**Kilimanjaro Project**), ambao unafadhiriwa na ''Mfuko wa Utafiti wa Serikali ya Ujerumani (German Research Foundation). Matokeo haya yanajumuisha matokeo ya utafiti wa miaka 30 uliofanyika katika mlima Kilimajaro ambao ulifanywana **Andreas na Claudia Hemp**. Dhumuni kuu la mradi wa KiLi ni kutafiti madhara ya mabadiliko ya tabia nchi na matumizi ya ardhi kwa bioanuai, mwingiliano wa viumbe hai na mfumo mzima wa mchakato wa ''biogeochemical".

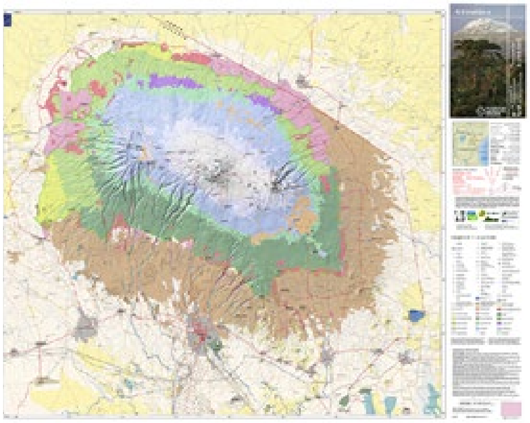
– Mradi huu ulipata ufadhili wa miaka nane (8). Kazi kubwa ambayo ndio msingi mkuu wa mradi ilikuwa ni uanzishwaji wa vitalu 65 (katika hivyo 13 ni vitalu elekezi) katika aina 13 tofauti za **makazi ya viumbe** (habitat), urefu wote wa mlima na matumizi mbalimbali ya ardhi katika upande wa kusini mwa mlima Kilimanjaro, hii ilienda sambamba na uanzishwaji wa bustani mbili za majaribio. Katika vitalu hivyo vya kitafiti, **watafiti walipima** kwa upana zaidi viumbe na viashiria muhimu vya uhai wa viumbe ikiwa ni pamoja na joto, kiasi cha mvua na mchakato wa ''biogeochemical" na jinsi mwingiliano wake unavyoweza kuleta madhara kwa bioanuai na tabia zake kwa ujumla.



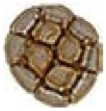
Ufuatao ni muhutasari wa matokeo ya jitihada za mradi

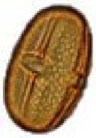
Ramani na atlas data:

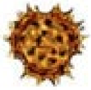
– Zaidi ya vitalu vya takwimu 1600 ambavyo vilifanyiwa utafiti wa kina vilitumika kuandaa **ramani ya kwanza ya mimea ya Mlima Kilimanjaro**. Ramani hii ilitumika katika utengenezaji wa ramani ya hali ya juu ambayo ilitumika kama msingi katika kuimarisha utalii mdogo, uhifadhi wa maliasili na mpango wa kuhifadhi mfumo wa Mlima Kilimanjaro. Mbali na uwasilishi wa hali ya juu wa mlima, ramani inaonesha kwa undani miundo mbinu ya hifadhi ya mlima Kilimanjaro na mtawanyiko wa mimea na matumizi ya ardhi.



– Pamoja na ramani hii, **atlas ya vichevuo** (pollen) na mbegu za mimea imekwisha andaliwa na inaonesha eneo zima la Africa. Katika atlas hii kumeoneshwa aina mbalimbali za vichevuo (pollen) na mbegu za mimea muhimu zilizopatikana katika maeneo ya barafu na Holocene jirani na mlima Kilimanjaro. Atlas hii itasaidia katika kurejesha uoto wa asili uliowahi kuwepo katika mlima Kilimanjaro na maeneo mengine ya Afrika Mashariki.



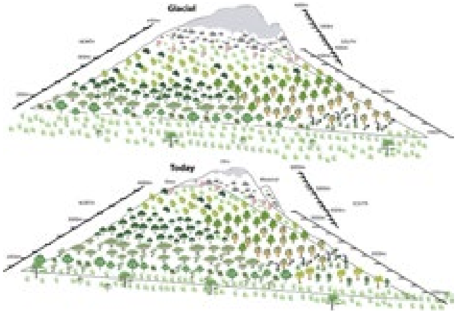




Climate and land-use change on Mt Kilimanjaro:

- **Temperature** drops linearly with elevation, **humidity and precipitation** are highest at intermediate elevations in the forest belt.
- The long **rains** got drier in recent years, while the short rains showed the tendency to get more abundant and to start approximately one month later, with highest rainfall amounts during December.
- **Evaporation** was highest in the lower forest belt where neither moisture nor energy limitations could be identified.
- **Vertical vegetation structure** displayed a unimodal elevation pattern, peaking at intermediate elevations in montane forests. Overall, vertical structure was consistently lower in modified than in natural habitat types.

- Long-term trend analysis of **NDVI, a measure of greenness**, showed for most areas above 3000 m a.s.l. increasing (greening) NDVI trends, which was mainly attributed to vegetation recovery after fires during the outgoing 20th century. Along the western mountain side, a strong decrease in NDVI resulted as a consequence of fire-driven downward migration of *Erica* bush along the upper slopes and massive land conversion processes affecting the lower slopes.
- Pollen records, giving information on the **vegetation history of Mt Kilimanjaro**, showed that during the Glacial, vegetation zones shifted downslope and were most likely reduced in total area due to colder and probably drier climate conditions; during the warming of the Holocene these vegetation zones moved upslope and showed an expansion. Unlike major parts of western equatorial Africa, where the humid forest area was reduced by 84 %, the mountains of east equatorial Africa seem to have received sufficient precipitation to sustain most of their forest taxa, even throughout the Last Glacial Maximum.



Effects of climate and land-use on soils and biogeochemical processes:

- Ecosystems at mid elevation (~2000 m) represented the interception zone of optimal moisture and temperature conditions throughout the year. High litter inputs and fast turnover controlled the **C sequestration** in these ecosystems, while climatic restraints on decomposition limited the C turnover in soils at lower (drought) and higher elevation (low temperatures).
- Land-use change from natural forests to agroforestry systems increased **litter macronutrient content and deposition** (N, P, K), thus enhancing biogeochemical fluxes. Carbon stabilization in these ecosystems and in the colline zone was reduced by about 30% by land-use intensification. Soil microbes in these ecosystems were less efficient in soil organic matter (SOM) decomposition but at the same time more demanding for new C sources.
- Maxima of **leaf litter decomposition** rates occurred between 1900 and 2500 m and were linked to the seasonal homogeneity of temperature and moisture availability.
- Highest **fine root biomass and necromass** was found in the upper mountain forest, the *Podocarpus*

Mabadiliko ya tabia nchi na matumizi ya ardhi katika mlima Kilimanjaro:

- Kwa kawaida **joto** hupungua jinsi unavyo panda juu mlima, unyevunyevu na **mvua** ni nyingi zaidi katika eneo la kati la mlima kwenye ukanda wa misitu.
- **Mvua ndefu** zimeambatana na ukame kwa miaka ya hivi karibuni, wakati mvua za vuli zimeonesha tabia ya kuongezeka na huanza mwezi mmoja baadae na mvua nyingi zipo mwezi wa Desemba
- **Evaporation** (utoaji wa maji katika majani ya mimea) ulikuwa mkubwa katika ukanda wa misitu ambapo uvukizi wa unyevu na nishati uliweza kubainika.
- **Muundo wa mimea** kwenda juu ulionesha kuwa mmoja, ukiongezeka katikati ya mwinuko katika misitu ya mlimani. Kwa ujumla muundo wa mimea kwenda juu ulikuwa mdogo katika maeneo yasiyo ya kiasili kuliko katika maeneo ya asili.

- Uchambuzi wa muda mrefu wa ukijani unaopimwa na kipimo cha **NDVI**, umeonesha ukijani kuongezeka katika maeneo mengi yaliyopo katika urefu wa mita zaidi ya 3000 katika mlima kutoka usawa wa bahari. Ongezeko la kipimo hiki cha NDVI kunaashiria kurejea kwa uoto wa kijani (mimea) ambao unachangiwa na kupungua kwa uchomaji misitu katika mlima Kilimanjaro katika karne ya 20. Katika upande wa magharibi mwa mlima, kumeonekana kuwa na upungufu wa kasi wa NDVI ikiashiria upungufu wa uoto wa mimea, hii imetokana na uchomaji wa moto unaofanyika chini ya mlima ambapo kuna mapito ya vichaka vya ukanda wa *Erica* pembezoni mwa mlima vilevile inachangiwa na mabadiliko makubwa ya matumizi ya ardhi ambayo yanapelekea madhara katika sehemu za chini ya mlima.
- **Rekodi za vichavushi** zinazoonesha historia ya uoto wa asili wa mlima Kilimanjaro ambayo zimebaini kwamba wakati wa kipindi cha barafu ukanda wa mimea ulihamia maeneo ya chini ya mlima, na inaonesha kuwa eneo la uoto lilipungua kwa sababu ya baridi na labda kwa sababu ya ukame. Wakati wa upashwaji joto wa Holocene ukanda wa mimea hii ulipanda juu na kuonesha kupanuka. Hii ni tofauti na misitu ya magharibi mwa Ikweta ambapo misitu ya mvua ilipungua kwa aslimia 84 %, milima ya Ikweta ya mashariki ilionesha kupata mvua ya kutosha na kuhifadhi aina mbalimbali za uoto wa misitu hata wakati wa barafu nyingi.

Madhara ya mabadiliko tabia ya nchi na matumizi ya ardhi kwenye udongo na mchakato wa biogeochemical:

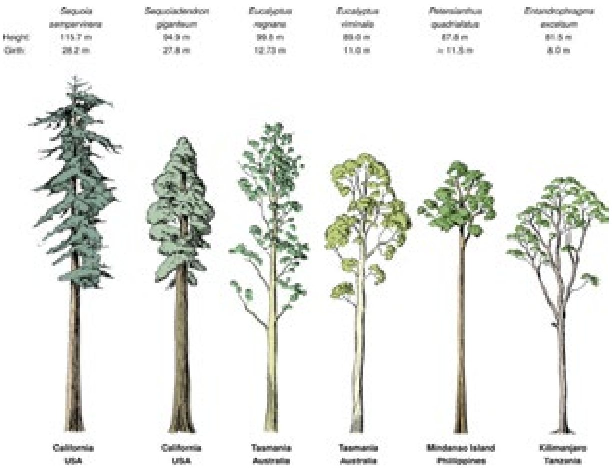
- Mifumo iliyopo katika eneo la urefu wa mlima kati ya takriban mita 2000 ilionesha kiasi cha kutosha cha hali ya unyevu na joto kwa mwaka mzima. Kiasi kikubwa cha majani yaliyodondoka na haraka kubadilika kuwa mboji yaliathiri kiasi cha ubadilishwaji wa gesi ya ukaa na kuwa **kabon** kwenye udongo katika mifumo hii, ila mlolongo wa kuibadilisha kabon uliathiri mabadiliko ya kabon kwenye udongo katika maeneo ya chini (kiangazi) na maeneo ya juu ya mlima (joto dogo).

forest. The ratio of fine root biomass to above ground biomass increased with elevation, showing that there was a shift of carbon allocation into the fine root system with increasing elevation.

- Land-use change, generally, resulted in a decrease of fine root biomass and necromass.
- Land-use change affected soil **properties and fertility**. A conversion of natural ecosystems to croplands reduced their productivity, leading to an average decrease in C stocks, with most of the decrease in the highly organic topsoil layers. This decrease in C contents was accompanied by a release of the greenhouse gas CO_2 from soil that negatively fed back on the climate system. Lower mountain forests at Kilimanjaro stored up to 10 times more soil organic carbon (SOC) per kg of soil in the upper 20 cm than agricultural sites did. In the savanna zone, SOC content was generally lower than at higher elevations. Here, soils lost about 60% of their SOC when savanna plains were converted into maize fields.
- Due to moderate soil moisture contents **N_2O emissions** of tropical montane forests were generally low. For the same reason forest soils were a significant sink of atmospheric CH_4. Land-use intensification increased soil **N_2O emissions** and decreased soil CH_4 uptake. Compared with reduced carbon stocks vegetation and soil, alteration of soil N_2O and CH_4 emissions following the conversion of forests into coffee plantations or homegardens were of lower importance in the overall ecosystem greenhouse gas balance.

Biodiversity of plants:

- All vegetation strata showed an increase in evolutionary relatedness, i.e. a loss of **phylogenetic diversity** with disturbance. Nevertheless, our results suggest that different vegetation strata experienced environmental harshness differently.
- The **tree species *Entandrophragma excelsum*** was found in the rare "*Newtonia* ravine forest type" around 1,625 m a.s.l. at the South-East slopes of Mt Kilimanjaro. This unique, very tall relict forest was recently found by us to harbour **Africa's tallest trees**, reaching up to 81.5m in height; the largest tree was estimated to be at least 850 years old.



- In contrast, the stout trees of ***Erica trimera*** at the upper treeline at 3950 m a.s.l. reached more than 10 m height and up to 53 cm in stem diameter; the estimated age of the larger individuals was over 800 years.

Effect of climate and land-use on plants:

- We found a unimodal pattern of **above ground tree biomass** over elevation, peaking in the montane region at 2000 – 2500 m with ~350 Mg ha^{-1}. Anthropogenic influence in the lower montane zone resulted in dramatic biomass decreases mainly due to deforestation.

- **Mabadiliko ya matumizi ya ardhi** kutoka misitu ya asili kuwa eneo la misitu na kilimo (agroforestry systems) yaliongeza kiasi cha majani yaliyodondoka na hivyo kuongeza virutubisho katika udongo (N, P, K), hivyo kuchangia ongezeko la ‘’biogeochemical’. Kiasi cha kabon katika ukanda wa ‘’colline” ilipungua kwa takribani asilimia 30 kwa sababu ya ongezeko la matumizi ya ardhi. Viumbe hai wadogo katika udongo katika mifumo hii walikuwa na ufanisi mdogo wa kubadilisha kiasi cha kabon (organic matter, SOM) na sambamba na hii waliharibu vyanzo vipya vya kabon katika udongo.
- Kiasi kikubwa cha kuozesha majani kwa wadudu katika udongo kilionekana katika urefu kati ya mita 1900 mpaka mita 2500 kutoka usawa wa bahari, na hii ilihusishwa na majira mazuri hasa upatikanaji wa **joto na mvua** muafaka.
- Kiasi kikubwa cha mizizi midogo na ‘’**necromass**” kilipatikana katika misitu iliyo upande wa juu wa mlima (*Podocarpus* forest). Uwiano wa wingi wa mizizi midogo na taka zilizo juu ya udongo uliongezeka jinsi urefu kwenda juu ya mlima ulivyoongezeka, ikionesha badiliko la mgao wa kabon katika mizizi midogo na jinsi ulivyoongezeka na urefu kwenda juu ya mlima.
- Kwa ujumla **mabadiliko ya matumizi ya ardhi** yalipelekea upungufu wa mizizi midogo na ‘necromass’.
- Mabadiliko ya matumizi ya ardhi yaliathiri tabia za udongo na rutuba. Ubadilishaji wa **mifumo ya asili** (misitu ya asili) kuwa maeneo ya mazao yalipunguza tija ya mifumo hiyo, na kupelekea kupungua kwa kiasi cha kabon iliyohifadhiwa hasa katika tabaka la juu la udongo.
- Kupungua kwa kiasi cha kabon kuliambatana na utoaji wa **gesi ya ukaa (CO2)** kutoka katika udongo ambayo ilileta matokeo hasi katika hali ya hewa kwa ujumla.
- Maeneo ya chini ya mlima Kilimanjaro yalihifadhi mpaka mara 10 zaidi ya kiasi cha **Carbon kwenye udongo (SOC)** kwa kila kg ya udongo katika sm 20 juu ya udongo kuliko maeneo ya kilimo. Katika ukanda wa savanna kiasi cha Carbon kwenye udongo (SOC) kilikuwa kidogo kuliko maeneo ya juu ya mlima. Katik maeneo haya udongo ulipoteza kiasi cha asilimia 60% ya SOC wakati nyanda za savanna zinapobadilishwa kuwa mashamba ya mahindi.

Bioanuai ya mimea:

- **Makundi ya mimea** yote yalionesha kuongezeka kwa kufanana na mimea ya zamani, tofauti zilizojitokeza zilisababishwa na ongezeko la shughuli za binadamu. Hata hivyo matokeo ya utafiti huu yanapendekeza kwamba makundi tofauti ya mimea yanahimili kitofauti usumbufu unaotokana na shughuli za kibinadamu.
- Mti ya *Entandrophragma excelsum* ulipatikana katika miti michache iliyobaki ambayo iko katika kundi la misitu liitwalo *Newtonia* ravine‘ ambayo inapatika katika urefu wa mlima ‘wa mita 1,625 kutoka usawa wa bahari kusini mashariki mwa mlima Kilimanjaro. Miti hii mirefu ya kipekee iligunduliwa na watafiti wa mradi huu kuwa ni mirefu sana **kuliko yote Afrika**, ikiwa na urefu wa mita 81.5 na mti mkubwa ulikuwa na takriban umri wa **miaka 850**.

- Mkabala na matokea haya miti imara aina ya *Erica trimera* inayopatikana juu katika mstari wa miti ambayo iko katika urefu wa mlima wa mita 3,950 kutoka usawa wa bahari ilikuwa na urefu wa mita 10 na upana wa sentimeta 53, ilikadiriwa kuwa na umri wa **miaka 800**.

Our estimates of biomass stocks over a wide range of habitat types highlighted the importance of tropical montane forest as an important carbon stock. Moreover, they demonstrated the large release of carbon following human land-use, particularly when tropical rainforest was converted to farmland or grassland for food and animal fodder.

- The number of small tree stems, representing **forest regeneration**, showed a unimodal distribution, peaking at mid elevation, and the number of species was decreasing with elevation.

- Agricultural land-use at lower elevation, namely maize fields, grasslands, homegardens and coffee plantations, reduced the number and diversity of stems dramatically, therefore impeding natural regeneration. Plots with former disturbance in form of fire and logging showed higher recruitment of stems and species than natural plots did, a proof of still ongoing succession and of the chance to return to the former state. However, the recovery to the old growth forest was by far not yet finished after a time span of 30–40 years, which shows the huge and long-lasting impact of anthropogenic disturbance in forests.
- Studying the effect of **selective logging** 30 years ago on *Ocotea* forest suggests a general greater regeneration, especially the higher relative abundance of small stems of *O. usambarensis* in selectively logged forests appeared promising for future forest recovery.
- We tested the combined effect of **temperature and water availability** on tropical African trees in a **transplant experiment** with 31 tree species including native as well as exotic ones. The results suggest that trees with a low specific leaf area, which indicates tough and well coated leaves, had increased survival and growth under savanna conditions. This might imply that global warming may favour species already preadapted to warmer temperatures, i.e. those with a low specific leaf area. Hence, our experiments suggest that forest management in East Africa should consider temperature-adapted species.

- In contrast, submontane plants, with higher specific leaf areas indicating thinner leaves, are likely to perform worse if future temperatures in the submontane region rise to those of the current savanna climate.
- We concluded from transplant experiments involving many sets of sibling plants that common plants in the lower parts of Kilimanjaro possess the preconditions to **adapt evolutionary to climate change**. However, whether plants will finally adapt or not will also depend on other factors such as change of precipitation and land-use, and biotic interactions with other plants (competition) or trophic levels (herbivory).

Madhara ya madiliko ya tabia nchi na matumizi ya ardhi kwa mimea:

- Matokeo yalionesha mwelekeo wa aina moja wa taka za miti ambayo iliongezeka jinsi urefu wa mlima ulivyozidi kuongezeka na ilikuwa nyingi zaidi katika ukanda wa mlima unaoanzia urefu wa **mita 2000 mpaka 2500** kutoka usawa wa bahari ikiwa na wastani wa uzito wa mg 350 kwa hekta moja. Shughuli za binadamu zilipelekea kupungua kwa kiasi kikubwa cha taka ya miti na katika ukanda wa chini wa mlima uliosababishwa na uharibifu wa misitu. Makadirio ya akiba ya taka ya miti katika sehemu kubwa ya mlima inaonyesha umuhimu wa misitu ya mlima ya kitropiki kama chombo muhimu cha kuhifadhi carbon. Matokeo haya pia yanaonesha ongezeko la kabon yanayotokana na ongezeko la mabadiliko ya matumizi ya ardhi hasa katika misitu ya mvua ya kitropiki ambayo imebadilishwa na kuwa sehemu za mashamba au nyanda za malisho.

- Idadi ya mashina ya **miti midogo** inawakilisha kurudi kwa uoto wa misitu, ambayo imeonesha msambao wa aina moja na kufikia kiwango cha juu katikati ya mlima, vilevile idadi ya aina za miti ilipungua jinsi urefu kwenda juu ya mlima ulivyoongezeka.
- **Matumizi ya ardhi** chini ya mlima kwa shughuli za kilimo, uwanda wa malisho, bustani za nyumbani na mashamba ya kahawa yanapunguza idadi na aina mbalimbali za miti kwa haraka sana na hivyo kuzuia uoto wa asili. Vitalu vya utafiti ambavyo mwanzoni vilikuwa na shughuli za binadamu kama moto na ukataji wa magogo ya miti yalionesha kukua kwa miti ambayo ipo katika misitu ya asili, ambacho ni kidhibitisho kwamba bado **mazingira yanaweza kurejea** katika uoto wake wa asili. Ila tu, kurejea kwa ukuaji wa misitu kulikuwa hakujamalizika kabisa miaka 30 – 40 iliyopita, hii inaonesha madhara makubwa ya muda mrefu ya uharibifu wa misitu unaofanywa na binadamu.
- Pamoja na madhara ya ukataji miti aina ya *Ocotea usambarensis* miaka 30 iliyopita, utafiti unaonyesha urejeaji mkubwa wa miti hii hasa tukiangalia wingi wa miti midogo ya aina hii katika maeneo yalipokatwa awali.
- Mradi ulifanya majaribio ya kuangalia madhara ya **jumla ya joto na mvua** katika miti ya Afrika katika tropiki ambapo aina zipatazo 31 za miti zilitumika zikiwemo za asili na zile za kigeni. Matokeo yalionesha kwamba miti yenye eneo dogo la majani ambayo inaonesha uimara wa majani, yalionekana kukua vizuri zaidi katika hali ya ukanda wa savanna. Inaonesha kwamba kuongezeka kwa joto duniani kunaweza pendelea aina za miti ambazo zinaota katika maeneo yenye joto. Kutokana na matokeo haya, mradi una pendekeza kwamba katika utawala mzima wa misitu, miti iliyozoea kuwa katika maeneo ya joto ipewe kipaumbele. Kinyume na matokeo ya awali, mimea yenye eneo kubwa la majani ilionesha kuwa na majani membamba, ambayo inaashiria kuwa miti hii haiwezi kuhimili ongezeko la joto katika ukanda wa mlima-kati (submontane).

- Ilihitimishwa katika jaribio hili kwamba **mimea ya kawaida** iliyopo katika eneo chini ya mlima Kilimanjaro ina sifa zote za kuweza kuhimili ongezeko la joto linalosababishwa na mabadiliko ya tabia nchi. Ila tu mimea hii itaweza kuhimili au kutohimili mabadiliko ya tabia nchi ikitegemea kubadilika kwa kiasi cha mvua na matumizi ya ardhi na mwingiliano kati ya viumbe hai na visababishi vya uhai.

Use of plants by people:

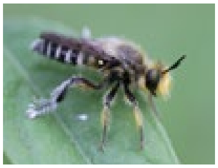
- 563 of the 962 plant species recorded in all study plots are known to be **usable by local people**. Of all 563 usable species 385 or 68 % belonged to the category of plants usable for traditional medicine. The second most frequent category was use as forage with 324 species (57.5%). 112 species (19.9%) were for use as fuel, either as firewood and/or charcoal. 103 species (18.3%) were for use as material for construction and making tools. 89 plant species (15.8%) were edible while 38 species (6.7%) were either preferred as shade trees in coffee and banana gardens or as ornamentals around homesteads. The proportions of usable plant species per plot followed a unimodal elevational pattern peaking in the lower to middle zones of the mountain.

- Human-influenced habitats had higher proportions of useful species for all usage categories, except for species used for construction and fuel wood which were more frequent in natural savanna and lower montane forest than in used habitats at these elevations.

Effect of climate and land-use on invertebrates and their ecosystem functions:

- Studies on the taxonomy of **Orthoptera (grasshoppers, locusts and crickets)** resulted in the description of a new subtribe of Conocephalinae including 4 new genera and over 30 new species; for other Orthoptera 15 new genera, about 130 new species and 4 subspecies were described. Drivers of the high species diversity of flightless Orthoptera in the area were shown to be past climatic fluctuations creating numerous closely related species of various genera in geologically young and old mountain ranges in East Africa during the past 1–2 million years.

- Orthopteran species richness on Chagga homegardens and organic coffee farms was higher than on conventional coffee farms.



- We found that the **biodiversity of bees** declined continuously with increasing elevation. However, also at the highest elevation bees could be found: a single species of apex-burrow bee (*Lasioglossum*, Halictidae) which occurred at extremely high abundances in the alpine vegetation zone.
- We conducted a pollinator (and bird/bat) exclusion experiment in coffee plantations: When looking at **pollination** we found that if pollinators had access to the coffee blossoms, the cherries were around seven percent heavier, which signified that the coffee was of higher quality.

- The highest species **diversity of millipedes** was found at mid-altitudes, around 1600 m a.s.l. Surprisingly, disturbed habitats had just as diverse millipede faunas as undisturbed ones; however, millipedes tended to be smaller in disturbed habitats.
- **Decomposer beetle abundances** declined almost linearly with elevation, and abundances of predator and herbivore beetles peaked at higher elevations and exhibited unimodal patterns. Temperature, not primary productivity, was the best predictor of abundance for most of the taxa and groups. Disturbance was only of minor importance.
- **Soil fauna activity** increased with elevation and was highest in *Erica* forests. In the wet seasons, feeding rates were higher in maize fields than in savanna sites, and in homegardens, coffee plantations and grasslands than in forest sites at similar elevations.

Matumizi ya mimea:

- Takribani aina ya mimea ipatayo 563 kati ya aina ya mimea 962 iliyo rekodiwa katika vitalu vya utafiti inatumika na wenyeji. Kati ya miti 563 aina 385 (68%) iko katika **kundi la mimea inayotumika kama madawa ya kienyeji**. Kundi la pili la mimea ni inayotumika kama chakula cha mifugo ambayo ni aina 324 (57%). Aina 112 (19.9%) zilitumika kama kuni au miti ya kuchoma mkaa. Aina 103 (15.8%) ilikuwa inaliwa wakati aina 38 (6.7%) aidha ilitumika kama miti ya kivuli katika mashamba ya kahawa na ndizi au miti ya maua katika maeneo ya makazi. Ulinganifu wa aina za mimea inayotumika kwa kila kitalu ilifuata mtawanyiko uleule ambao uliongezeka chini kwenda katikati ya mlima.
- Shughuli za binadamu zilionesha kudhuru maeneo yenye mimea inayotumiwa zaidi isipokuwa miti iliyotumika katika ujenzi na ile inayotumika kama **kuni** au kama miti ya **kuchoma mkaa** ambayo ipo katika maeneo ya savanna na chini ya mlima katika misitu ya mlima.

Madhara ya mabadiliko ya tabia nchi na matumizi ya ardhi kwa invertebrata na mifumo kazi yake:

- Utafiti wa wadudu ambao wapo katika taxonomi ya Orthoptera (**panzi, nzige na nyenje**) umeleta matokeo mazuri ambapo kabila mpya ya Conocephalinae ambayo ina genera 4, aina mpya zaidi ya 30 ziligunduliwa. Kwa panzi wengine genera 15 mpya, aina mpya 130 na aina ndogo 4 zilielezwa kitaalam. Vikwazo vinavyoathiri hawa wadudu wasioruka katika hili eneo vilionekana kuwa ni mabadiliko ya mara kwa mara ya hali ya hewa kwa wakati uliopita na kusababisha aina nyingi za wadudu hawa kutofautiana kidogo katika genera nyingi kijiografia hasa katika milima kijana na milima ya kale katika Afrika Mashariki kwa kipindi cha miaka milioni 1 – 2 iliyopita.

- Hawa wadudu aina ya **panzi** walipatikana kwa wingi katika maeneo ya bustani ya wachagga na mashamba ya kiasili ya kahawa kuliko katika mashamba ya kisasa.
- Matokeo yalionesha kuwa bioanuai ya **nyuki** ilipungua jinsi urefu kwenda kilele cha mlima ulivyoongezeka. Ila tu nyuki aina ya 'apex-burrow' (*La sioglossum*, Helictidae) walipatikana katika eneo la alpine ambalo liko juu mlimani.
- Utafiti wa uchevushaji wa mimea (**ndege/popo**) katika mashamba ya kahawa ulifanyika na kungundulika kwamba kama hawa ndege na popo wakipata fursa ya kuchevusha maua ya mimea, tunda la mmea linaongezeka uzito kwa asilimia 7, vilevile ilionesha ubora wa kahawa.
- Utafiti ulionesha pia kuwa **aina nyingi za millipede** (ichongololo) zilipatikana zaidi katika urefu wa mita 1600 kutoka usawa wa bahari. Cha kushangaza ni kwamba maeneo yaliyo sumbuliwa na shughuuza kilimo yalikuwa na aina nyingi za wadudu hawa kama maeneo ambayo hayaja sumbuliwa ila millipede waliopatikana katika maeneo yaliyo sumbuliwa walikuwa na maumbo madogo.
- Wingi wa wadudu wanao ozesha taka walipungua jinsi urefu kwenda juu kileleni mwa mlima ulivyoongezeka. Ila **wadudu wawindao na walao majani** walionekana kwa wingi katika maeneo ya juu ya mlima. Joto lilikuwa kiashiria kizuri cha wingi wa hawa wadudu. Bugudha inayotokana na shughuli za kibinadamu ilionesha usumbufu na madhara madogo katika upatikanaji wa hawa wadudu.
- **Wadudu wa kwenye udongo** waliongezeka jinsi urefu kwenda juu ya mlima ulivyoongezeka na walikuwa wengi zaidi katika ukanda wa misitu ya *Erica*.

- Decomposition experiments indicated that **decomposition rates** were controlled by humidity and temperature, but not by invertebrates. Along the elevational gradient decomposition rates had a peak at mid-elevations (ca. 2000 m a.s.l.) in undisturbed habitats; in disturbed habitats, decomposition rates decreased with elevation. Along the land-use gradient, decomposition was highest in forest sites, followed by homegardens and coffee plantations, and only low decomposition rates in grassland sites.

Effect of climate and land-use on vertebrates and their ecosystem functions:

- Resources were the most important factor determining **bird diversity** along the elevational gradient. Temporal changes in bird diversity in the past 20 years indicated that the temperature increase over the last twenty years resulted in an average increase of bird abundance at high elevations. Additionally, we found that climate and land-use interacted in their effects on bird diversity. Specifically, high temperatures and high land-use intensity resulted in a higher change in bird communities than expected from their single effects, suggesting that climate change could exacerbate impacts of land-use on biodiversity and vice versa.
- The diversity of **fruit-eating bird species** determined how many fruits were eaten and potentially dispersed in the different habitat types. Birds and bats also acted as **predators** of herbivorous insects. The experimental exclusion of birds and bats from coffee plants led to a reduction in fruit set of ca. 9%. Hence, birds and bats are important pest control agents that significantly increased coffee yield. Together with the above results on pollinators, the exclusion experiments showed that the effects of pollination and pest control complement each other and contributed to coffee yields: birds and bats provided more cherries; bees and other pollinators ensured better quality of coffee.

- We advise to maintain natural habitats and semi-natural habitats next to agricultural areas to ensure a high diversity of pollinators, birds and bats, which contribute to coffee yields.
- Studying **large mammals** with camera traps showed that the species richness of mammals peaked at around 2500 m in the forest belt. A very exciting finding was that we could film the endangered antelope species **Abbott's Duiker** for the very first time on Mt Kilimanjaro. This elusive antelope was so far only found on some isolated mountain massifs in the East and South of Tanzania and until now, the distribution pattern of this antelope on Mt Kilimanjaro has not been known. We documented the Abbott's Duiker throughout the forest belt from 1,900 to 3,800 m.
- Outside Mt Kilimanjaro National Park, we found large mammals only in protected habitats like the Lake Chala Conservation Area and not, for example, on other unprotected study sites in the savanna. This finding underpins the crucial importance of protected areas for the conservation of large mammals.

Katika kipindi cha masika walionesha kula zaidi katika mashamba ya mahindi katika ukanda wa savanna na bustani za nyumbani, mashamba ya kahawa na maeneo ya uwanda wa malisho zaidi kuliko katika misitu katika ukanda huohuo.

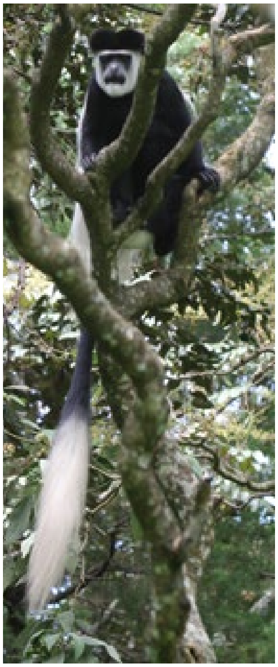
- Jaribio la uozeshaji wa taka lilionesha kwamba uharaka wa kuozesha taka ulitegemea unyevu na joto ila sio kwa **wadudu aina ya invertebrata**. Ukichukulia urefu kwenda juu ya mlima, katika maeneo yasiyo na shughuli za kibinadamu, uharaka wa kuoza kwa taka ulifikia kikomo cha juu katikati ya urefu wa mlima hasa katika mita 2000 kutoka usawa wa bahari, wakati katika maeneo yenye bugdha za binadamu uharaka wa kuoza kwa taka ulipungua jinsi urefu kwenda juu ya mlima ulivyoongezeka. Ukiangalia mkingamo wa matumizi ya ardhi, kuoza kwa taka kulionekana katika misitu ikifuatiwa na bustani za nyumbani, mashamba ya kahawa na ulikuwa mdogo zaidi katika maeneo ya uwanda wa malisho.

Madhara ya mabadiliko ya tabia nchi na matumizi ya ardhi kwa vetebrata na mifumo kazi yake:

- Upatikanaji wa rasilimali ulikuwa ni kigezo muhimu katika upatikanaji wa aina mbalimbali za **ndege katika mkingamo wa mlima Kilimanjaro**. Mabadiliko ya majira yanaathiri aina mbalimbali za ndege pia. Katika kipindi cha miaka 20 iliyopita yalionesha kwamba ongezeko la joto lilipelekea ongezeko la aina mbalimbali za ndege katika maeneo ya juu ya mlima Kilimanjaro. Vilevile, mabadiliko ya hali ya hewa na mabadiliko ya matumizi ya ardhi vilidhuru uwepo wa aina mbalimbali za ndege.

- Ilibainika kwamba joto kubwa na **mabadiliko makubwa** ya matumizi ya ardhi viliathiri mabadiliko ya jamii za ndege zaidi ya ilivyotegemewa, hii inaonesha kwamba mabadiliko ya tabia nchi yanaongeza kasi ya madhara ya matumizi ya ardhi ambayo yanaathiri bioanuai za ndege na vinginevyo.

- Uwepo wa aina mbalimbali za aina za ndege wanaokula matunda unaonesha ni kwa kiasi gani matunda yaliliwa na kusambazwa katika maeneo mbalimbali porini. **Ndege na popo** vilevile wanajulikana kwa kuwala wadudu wanaokula majani. Katika jaribio lililofanyika ambapo ndege na popo waliondo lewa, matokeo yalionesha kupungua kwa uzalishaji wa kahawa kwa asilimia 9. Hivyo basi, ndege na popo ni muhimu sana katika **kupunguza wadudu waharibifu** wa mazao kama zao la kahawa. Pamoja na matokeo ya hapo juu ya vichevushi vya mimea, jaribio la kuwaondoa ndege na popo linaonesha kwamba uchevushaji na uzuiaji wa wadudu waharibifu wa mazao ni vitu viwili vinavyotoshelezana na kuchangia katika kuongeza uzalishaji wa mazao kama zao la kahawa: **Ndege na popo wanasaidia kahawa** kuwa na rangi nzuri; wakati nyuki na vichevushaji vingine vinahakikisha uwepo wa kahawa iliyo bora.

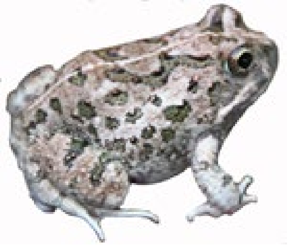


- Hivyo inashauriwa kuwa na uoto wa asili na hata ule wa kati karibu na mashamba ya kilimo ili kuhakikisha kwamba **kuna aina mbalimbali za vichevusha mimea** na vidhibiti wadudu wanao haribu mazao.

- **Orthoptera serve as ideal bioindicators** for land-cover and climate changes. Based on the endemicity patterns of forest Orthoptera, negative consequences were predicted due to the effects of isolation, in particular for larger forest animals. Kilimanjaro is becoming an increasingly isolated ecosystem with far-reaching consequences for diversity and endemism.

- Most **insectivorous bats** were found between 1100 and 1750 m a.s.l. in natural habitats. Bat species composition changed significantly along both elevational and human disturbance gradients. Some bat species seemed to be particularly associated with forested areas and thus were likely to react sensitive to further loss of forest cover in the region.

- Regarding the **total species richness of all species, plants and animals**, the strongest relationship was found between temperature and species diversity, i.e. the warmer the plot the more species on the plot.

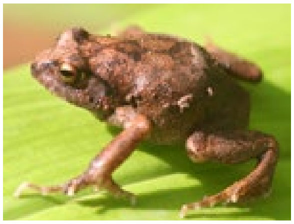


- A total of 21 **amphibians** was recorded during the first survey ever conducted for this group on Mt Kilimanjaro.
- A total of 81 species of **snails** belonging to 17 families are known for Kilimanjaro. 30 species are endemic to Kilimanjaro and another five restricted to the Mts Kilimanjaro/Meru area. During our survey 60 species were collected, with one species *Atoxon* near *kiboense* new to science. 11 species were documented for the first time to occur on Kilimanjaro.

To conclude, the Kilimanjaro project shows that climate and land-use change had profound impacts on biodiversity and ecosystem functions. Most importantly, the negative effect of land-use change on biodiversity and ecosystem functions depended on climate and vice versa. Overall, most studies provided evidence that **biodiversity matters for ecosystem functioning**.

- **Utafiti wa wanyama wakubwa** kwa kutumia kamera maalum umeonesha kwamba aina nyingi za wanyama ziliongezeka hasa katika urefu wa mlima wa mita 2500 kutoka usawa wa bahari katika ukanda wa misitu. Matokeo yakusisimua ni kwamba tuliweza kutengeneza sinema ya swala hadimu aitwaye **Abbott's Duiker** kwa mara ya kwanza katika mlima Kilimanjaro. Swala huyu hadimu huwa anapatikana katika milima iliyojitenga mashariki na kusini mwa Tanzania, na mpaka sasa mwonekano wa mnyama huyu katika mlima Kilimanjaro haukuwahi kujulikana. Mnyama huyu alionekana katika ukanda wa mlima katika urefu wa kati ya mita 1,900 mpaka 3800 kutoka usawa wa bahari.
- **Panzi** wanatumika kama kielelezo cha mabadiliko ya tabia nchi na matumizi ya ardhi. Kupitia upatikanaji wa panzi hasa katika misitu, matokeo hasi yali hisiwa hasa kwa wanyama wakubwa waishio katika maeneo ya misitu iliyojitenga. Mfumo wa ikolojia wa Kilimanjaro umekuwa ukiongezeka kujitenga na hivyo kuhofiwa kupoteza mseto wa viumbe.
- **Nje ya Hifadhi ya Mlima Kilimanjaro**, ni maeneo tu yale yaliohifadhiwa yalionekana kuwa na wanyama wakubwa, kwa mfano Eneo lililohifhadhiwa la ziwa Chala, na siyo, katika maeneo ambayo hayajahifadhiwa katika ukanda wa savanna. Matokeo haya yanatia msisitizo umuhimu wa maeneo yaliyo hifadhiwa kwa uhifadhi wa wanyama wakubwa.

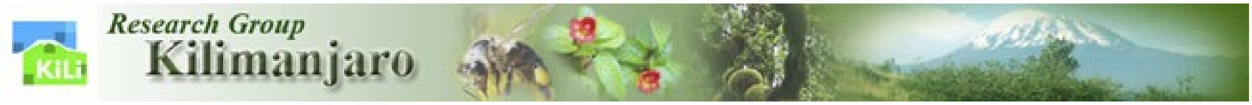
- Popo walao wadudu walipatikana katika eneo la mlima katika urefu wa mita 1100 na 1750 kutoka usawa wa bahari katika hifadhi za asili. Aina mseto za popo zilibadilika kwa kiasi kikubwa sambamba na kuongezeka kwa urefu wa mlima na vilevile kuongezeka na shughuli za binadamu. Baadhi ya aina za popo zilionesha kuwa na mahusiano na maeneo ya misitu na hivyo popo hawa watatoweka endapo uharibifu wa misitu utanendelea.



- Kwa kuangalia kwa ujumla wake ni kwamba, kuna **mahusiano kati ya wingi wa aina za mimea na wanyama na joto**. Vitalu vilivyokuwa na joto jingi vilikuwa na aina nyingi za wanyama na mimea pia.
- Katika utafiti wa **amphibia (chura, kilo)** ambao ni wa kwanza na wa aina yake katika mlima Kilimanjaro, jumla ya aina 21 za amphibia zilirekodiwa.

- Aina 81 za **konokono** wa nchi kavu zimepatikana katika mlima Kilimanjaro. Kati ya hizo aina 30 zinapatikana katika maeneo ya milima ya Kilimanjaro na aina tano zinapatikana katika maeneo ya milima ya Kilimanjaro na Meru tu.

Hitimisho, Mradi huu umeonesha kwamba mabadiliko ya tabia nchi na matumizi ya ardhi yana mchango mkubwa katika bioanuai na mifumo kazi ya hifadhi ya mlima Kilimanjaro. Suala muhimu zaidi nikwamba, madhara hasi yanayotokana na mabadiliko ya matumizi ya ardhi katika bioanuai na mifumo kazi yake yanategemea zaidi tabia nchi na vinginevyo. Kwa ujumla, utafiti umetoa kielelezo kwamba uhifadhi wa bioanuai ni muhimu ili kuleta mifumo kazi.



The KiLi Project: Kilimanjaro ecosystems under global change: Linking biodiversity, biotic interactions and biogeochemical ecosystem processes

INTRODUCTION

Tropical mountain ecosystems are known for their rich vegetation and diverse animal communities which supply a multitude of goods and beneficial ecosystem services to human societies. In the KiLi Research Unit a team of Tanzanian and European researchers studied the consequences of climate and land-use change on the ecosystems of Mt Kilimanjaro. By inventorying the flora and fauna a contribution to the description of Tanzania's natural richness and the mitigation of negative effects of ongoing global change was made. The results of the KiLi Research Unit obtained from research between 2010 and 2018 are summarized in this booklet.

MOUNTAINS FOR HUMAN WELL-BEING

Mountains occupy a quarter of the terrestrial surface, host at least one third of the terrestrial plant diversity, and supply resources and ecosystem services to more than half of the world's human population. Biodiversity and the provision of resources and ecosystem services are largely depending on intact natural ecosystems on mountains. For example, an intact forest cover prevents soil erosion and stabilizes water flow, which sustains agriculture and hydroelectricity at the foothills of mountains. Crops like beans, tomatoes and coffee are depending to a certain degree on pollination and pest control services supplied by bees, birds and bats from adjacent natural vegetation, respectively.

Biodiversity, ecosystem processes and services provided to human societies are threatened by the combined impact of global warming and the destruction of natural and semi-natural habitats.

Due to narrow temperature and habitat ranges of species, steep slopes and extreme climatic conditions (e.g. very high rainfall), tropical mountain ecosystems are expected to be especially vulnerable to these drivers of global change.

THE KILI PROJECT

The KiLi Research Unit was established on Mt Kilimanjaro since this volcano is ideally suited for global change research because of the following reasons: It shows a world-wide unique altitudinal range of over 5000 m with climate and vegetation zones changing from tropical savanna to afroalpine grassland. Furthermore, apart from natural ecosystems several different land-use systems occur that include both intensive annual monocultures and diverse traditional agroforestry systems retaining a semi-natural forest structure.

The highest mountain of Africa acts as a water tower feeding major river systems, plays a dominant role in regional climate regulation, and provides many other important ecosystem services to local human societies. Its melting ice cap, though rather caused by decreasing precipitation than by increasing temperature, has become a global symbol for the accelerating trend of global warming.

The KiLi Project, a joint research effort of Tanzanian and German scientists funded by the German Science Foundation (DFG), studied the influence of climate and land-use change on biodiversity and multiple ecosystem processes on Mt Kilimanjaro. Scientists from different research disciplines comprising climate and soil sciences as well as botany and zoology studied Mt Kilimanjaro´s biodiversity and ecosystem processes on 65 research plots situated on five transects from savanna to alpine habitats. Each subproject was led by European scientists in close collaboration with Tanzanian counterparts.

Structure of the KiLi Research Unit

The KiLi Research Unit consisted of seven subprojects with a different background ranging from climate, soil, botany to zoology. Two Central Projects were responsible for management of the collected data and for coordination of the project in Germany and Tanzania.

Phases 1 & 2 (2010–2016)

KiLi Central Project 1: Management, administration and coordination of the KiLi Research Unit.

Project leaders & counterparts: Ingolf Steffan-Dewenter, Andreas Hemp, Markus Fischer, Victor Kakengi, Julius Keyyu, Markus Borner. Project coordinator: Claudia Hemp.

KiLi Central Project 2: Central database, communication platform and data synthesis of the KiLi Research Unit.

Project leaders & counterparts: Ingolf Steffan-Dewenter, Andreas Hemp, Markus Fischer, Thomas Nauß, Katrin Böhning-Gaese. Data manager Jie Zhang. PostDoc: Marcell Peters.

Subproject 1: Climate Dynamics of the Kilimanjaro Region. Project leaders & counterparts: Thomas Nauß, Tim Appelhans, E. Lufungulo.

Subproject 2: 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. Project leader: Bernd Huwe, Dietrich Hertel, Christina Bogner.

Subproject 3: Linking nutrient cycles, land-use and biodiversity along an altitudinal gradient at Mt Kilimanjaro. Project leaders & counterparts: Yakov Kuzyakov, Ralf Kiese.

Subproject 4: Plant diversity and performance in relation to climate and land-use on Mt Kilimanjaro: communities, species, populations, ecological genetics.

Project leaders & counterparts: Markus Fischer, Andreas Hemp, Reiner Zimmermann, Jouko Rikkinen, Margaret Mollel (TPRI).

Subproject 5: Plant functional traits translated into vegetation dynamics – Responses to environmental factors and effects on ecosystem functions of the Kilimanjaro region. Project leaders & counterparts: Michael Kleyer, Andreas Huth, Pius Zebhe Yanda.

Subproject 6: Biodiversity and ecosystem functioning: birds and bats as seed dispersers and arthropod predators. Project leaders & counterparts: Katrin Böhning-Gaese, Elisabeth Kalko, Matthias Schleuning, Marco Tschapka, Kim M. Howell.

Subproject 7: Effects of climate und land-use change on biodiversity and ecosystem functioning of pollinators and decomposers. Project leaders & counterparts: Ingolf Steffan-Dewenter, Roland Brandl, Mary Gikungu, Paul J. Msemwa.

Associate Project I: Studies on late Quaternary environmental dynamics (vegetation, biodiversity, climate, soils, fire and human impact) on Mt Kilimanjaro.

Project leaders & counterparts: Hermann Behling, Lisa Schüler-Goldbach, Andreas Hemp.

Phase 3 (Synthesis projects) (2016–2018)

Central Coordination Project: Management, administration and coordination of the KiLi Research Unit. Project leaders: Katrin Böhning-Gaese, Andreas Hemp, Markus Fischer.

Central data base project: Central database and communication platform of the KiLi Research Unit. Project leaders: Ingolf Steffan-Dewenter, Thomas Nauss, Katrin Böhning-Gaese.

Synthesis Project Syn 1: Biodiversity and ecosystem remote sensing. Project leaders: Thomas Nauss, Tim Appelhans, Roland Brandl, Andreas Hemp, Andreas Huth.

Synthesis Project Syn 2: Functional relationships between land-use, climate and biogeochemical cycles. Project leaders: Ralf Kiese, Yakov Kuzyakov, Andreas Huth, Dietrich Hertel, Christina Bogner.

Synthesis Project Syn 3: Drivers and ecosystem consequences of plant community assembly. Project leaders: Andreas Hemp, Michael Kleyer, Markus Fischer.

Synthesis Project Syn 4: Predicting ecosystem functions from functional diversity and plant-animal interaction networks. Project leaders: Katrin Böhning-Gaese, Matthias Schleuning, Marco Tschapka.

Synthesis Project Syn 5: Drivers of biodiversity and biodiversity-ecosystem functioning relationships along climate and land-use gradients. Project leaders: Ingolf Steffan-Dewenter, Roland Brandl, Marcell Peters.

Synthesis Project Syn 6: Scientific foundations of conservation and sustainable use of biodiversity and ecosystem services. Project leaders: Markus Fischer, Andreas Hemp.

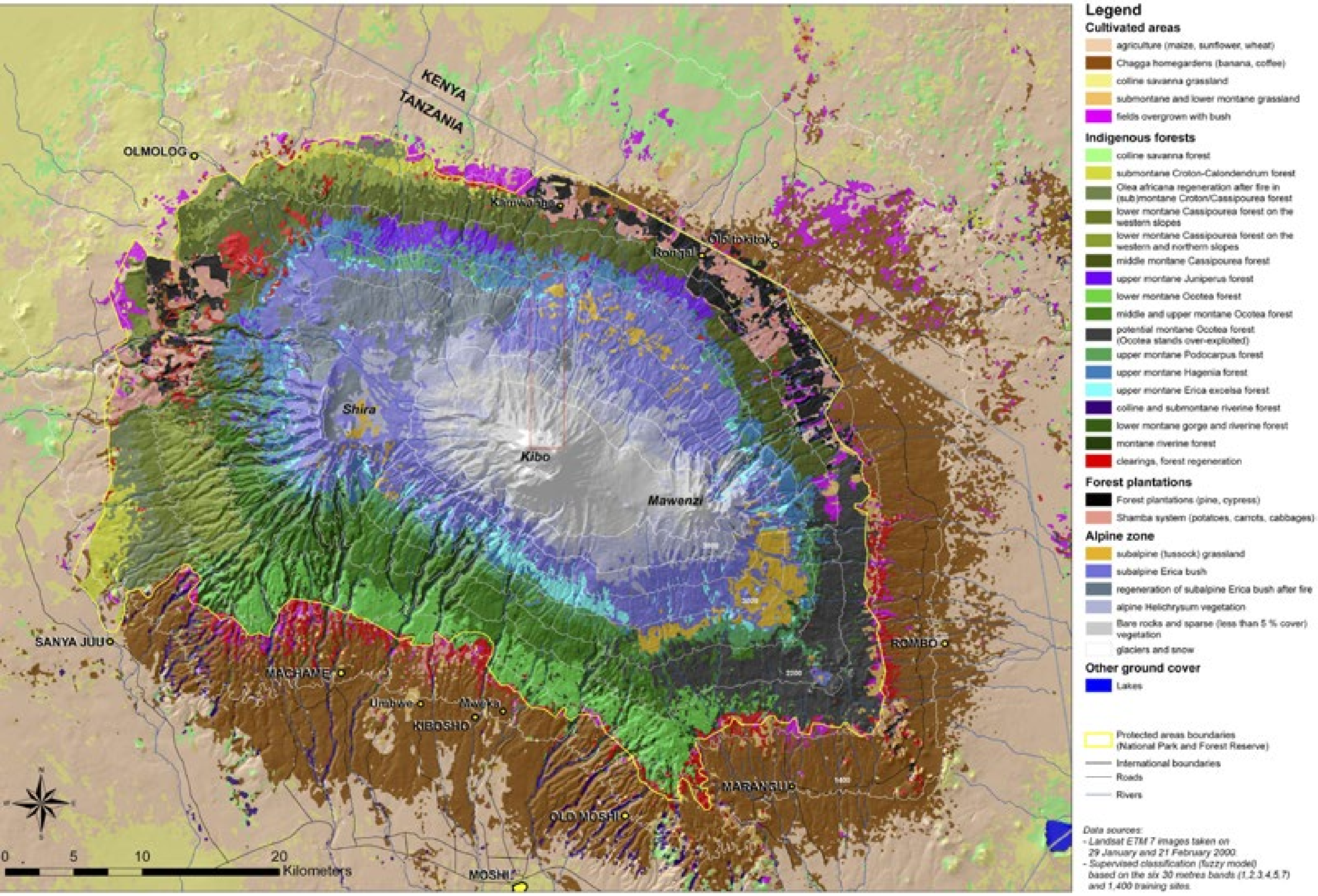
Overview of the vegetation and climate of Kilimanjaro

Mt Kilimanjaro, a relic of an ancient volcano, rising from the savanna plains at 700 m elevation to a snow-clad summit of 5895 m altitude is located 300 km south of the equator in Tanzania on the border with Kenya. Its climate is characterized by a bimodal rainfall pattern with the long rains from March to May forming the main rainy season, and the short rains centred around the month of November of the small rainy season. The foothills of the southern slopes receive an annual rainfall of 800–900 mm and the lower slopes at 1500 m receive 1500–2000 mm. The forest belt between 2000 and 2300 m receives partly over 3000 mm, which is more than on other high mountains of East Africa. In the alpine zone the precipitation decreases to 500 mm. According to the different climatic conditions several vegetation zones are apparent on the southern slopes of Mt Kilimanjaro. Between 700 and 1000 m a.s.l. the dry and hot colline savanna zone stretches around the mountain base, where most areas are farmed with maize, beans and sunflowers, in West Kilimanjaro with wheat. Around Lake Chala at the eastern foot of the mountain, and around Ngare Nairobi of West Kilimanjaro, savanna grasslands are still intact. The main cultivation zone with its coffee–banana plantations, the actual study area is located between 1000 and 1800 m. Natural forests cover an area of about 1000 km^2 on Mt Kilimanjaro. In the lower parts of the southern slope the montane forests are characterized by the tree *Ocotea usambarensis* and higher up in the cloud forest zone by *Podocarpus latifolius*, *Hagenia abyssinica* and *Erica excelsa*. On the drier northern slope the vegetation zonation starts with *Croton-Calodendrum* forests, *Cassipourea* forests at mid-altitudes and *Juniperus* forests at higher altitudes. At around 3100 m the forests are replaced by *Erica* bush. At an altitude of about 3900 m the *Erica* heathlands grade into *Helichrysum* cushion vegetation that reaches up to 4500 m. Higher altitudes are very poor in vegetation while the highest elevations of Kibo peak are covered with glaciers. Kilimanjaro harbours, on the one hand, wilderness areas (savanna, tropical montane rainforest, afroalpine areas), but on the other comprises extremely densely populated areas (in the coffee-banana belt). It encompasses completely different land-use systems (e.g., sustainable agroforestry systems, intensely used crop fields and coffee plantations, pastoralism). Tourism by 'normal' climbing tourists and a growing number of 'ecotourists' is increasing steadily and about 50,000 people attempt to climb Kibo every year. Moreover, the life styles of the different tribes living on the mountain are completely different. The Chagga live of agroforestry in their traditional multi-crop homegardens on the mountain slopes, while the Masai are mainly supported by cattle husbandry and increasingly also by monoculture maize fields on the foothills. Finally, because of its melting glaciers Kilimanjaro is an icon of global change, which attracts worldwide interest.

Table 1. The major altitudinal zones with their main natural vegetation and land-use at the southern slopes of Mt Kilimanjaro

Altitude	Natural vegetation
>4600	Upper alpine and nival zone bare of vegetation
4000–4600	Alpine *Helichrysum* vegetation
3200–4000	Subalpine *Erica* bushland and forest
2800–3200	Upper montane *Ocotea* (Camphor) forest
1800–2800	Middle montane *Ocotea* (Camphor) forest
1100–1800	Submontane and lower montane forest
700–1100	Lowland forest, savanna

Fig. 1. Kilimanjaro seen from the southern side, showing its marked vegetation zones.



Data sources:
- Landsat ETM 7 images taken on 29 January and 21 February 2000.
- Supervised classification (fuzzy model) based on the six 30 metres bands (1,2,3,4,5,7) and 1,400 training sites.

Fig. 2. Vegetation map of Mt Kilimanjaro based on about 1500 ground plots and intensive field surveys of about 20 years.

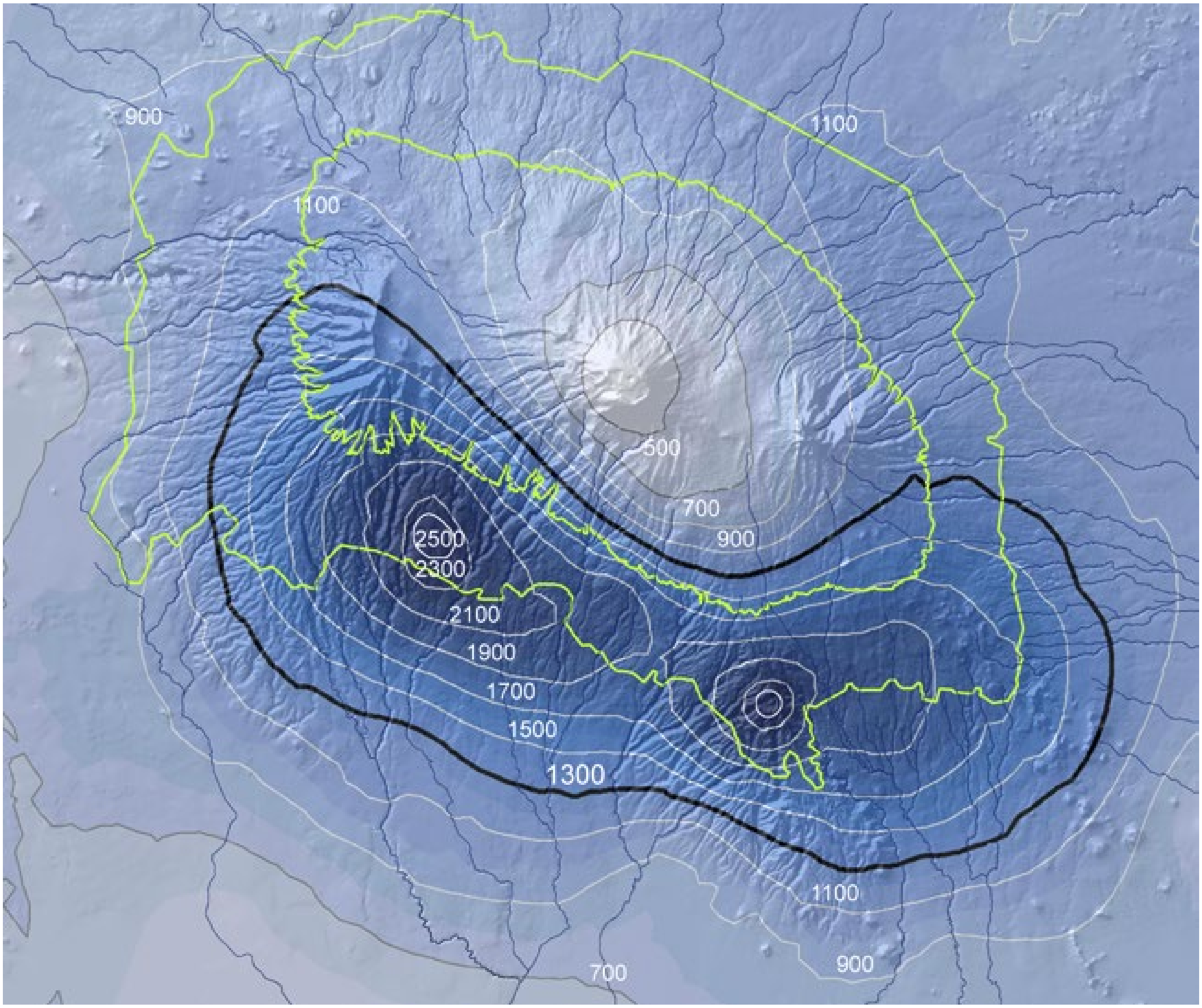


Fig. 3. Rainfall map based on over 50 weather stations installed around the mountain from 1996 onwards. Numbers indicate average precipitation in millimetre per year.

Rainfall map of Kilimanjaro

Evaluation of climatic data (mainly rainfall, temperature, humidity) obtained from over 50 weather stations, distributed on 30 transects from the savanna to the alpine zone providing the first data from the Kilimanjaro rain forest belt, made it possible to calculate a rainfall map for the whole of Kilimanjaro (Fig. 3).

Study design of the KiLi Project

13 different types of ecosystems were studied by the KiLi Project. These 13 ecosystem types are distributed along the natural elevational gradient from savanna to the alpine zone, and they represent gradients of human disturbance from natural to disturbed (at higher elevation in the case of burned *Erica* sites and of logged *Ocotea* sites; at lower montane and submontane elevation from natural rain forest, via traditionally used Chagga homegardens, to plantations of coffee; at the lowest elevations from natural rain forest via traditionally used Chagga homegardens and natural savanna to maize fields) (Fig. 1).

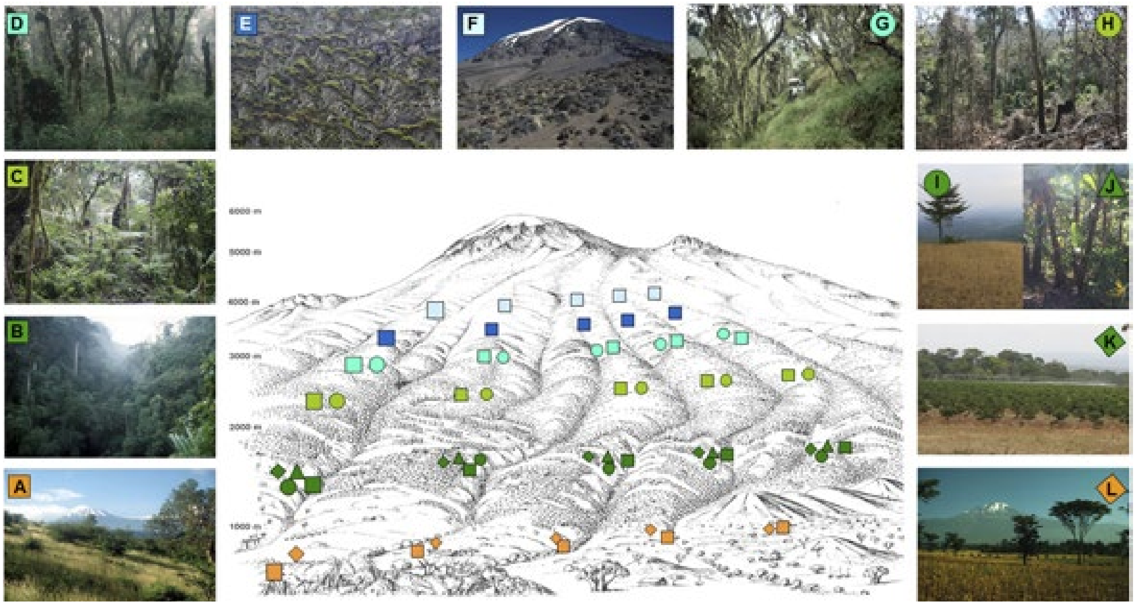


Fig. 1. Schematic representation of the general study design of the KiLi Project. The KiLi Project collects data in the 12 major ecosystem types of Kilimanjaro, 6 natural (**A–F**, squares) and 6 disturbed ecosystems (**G–L**, other symbols). 12 larger symbols represent the focal study plots (one for each ecosystem type) on which more elaborate measurements and experiments were conducted. From 2013 onwards 13 habitat types were investigated. **A:** Colline savanna **B:** Submontane-lower montane rainforest **C:** Camphor Forest **D:** *Podocarpus* forest **E:** *Erica* forest **F:** alpine *Helichrysum* vegetation **G:** *Erica* forest replacing *Podocarpus* forest after fire **H:** Logged Camphor forest **I:** Grassland **J:** Chagga homegarden **K:** Coffee plantation **L:** Maize field. All ecosystem types are represented by 5 replicate study plots.

Central research concept and objectives

The overall goal of the planned research unit was to understand the combined effects of climate and land-use change on biodiversity, biogeochemical and biotic ecosystem processes and related ecosystem services. Mt Kilimanjaro in Eastern Africa was selected for study which, as a world heritage site with immense biodiversity, symbolizes the impacts of global warming and anthropogenic disturbance on nature. It provides a superior study region to establish an innovative global change research programme with long-term perspectives and broad-scale relevance for tropical ecosystems. Mt Kilimanjaro combines a steep climatic gradient from tropical savanna to alpine shrubland with a broad range of natural and human-modified habitat types at different altitudes. This setting enables to study the complex interplay between climate conditions, habitat disturbance and land-use change, nutrient, water and carbon dynamics, primary productivity, biodiversity and biotic interactions. Tanzanian and German scientists from different disciplines closely collaborated on joint study sites.

Table 2. KiLi research plots (Plot), their acronyms, type of plot, elevation (elev.), annual amount of precipitation (rain), and mean annual temperature (MAT).

Plot	Type of plot	Elev.	Rain	MAT
Cof1	Coffee Plantation	1307	1641	19,0
Cof2	Coffee Plantation	1360	1931	18,8
Cof3	Coffee Plantation	1300	1596	19,0
Cof4	Coffee Plantation	1120	1269	20,0
Cof5	Coffee Plantation	1660	1824	17,0
Sun1	Coffee Plant. open	1150	983	19,9
Sun2	Coffee Plant. open	1360	1913	18,8
Sun4	Coffee Plant. open	1160	1328	19,9
Sun3	Coffee Plant. open	1330	1592	18,9
Gra1	Grasland	1660	2733	17,0
Gra2	Grasland	1750	2016	16,5
Gra3	Grasland	1480	1728	18,0
Gra4	Grasland	1310	1410	19,0
Gra5	Grasland	1300	1111	19,0
Hom1	Homegarden	1640	2603	17,0
Hom2	Homegarden	1150	1587	19,9
Hom1	Homegarden	1640	2603	17,0
Hom2	Homegarden	1150	1587	19,9
Hom3	Homegarden	1840	2140	15,9
Hom4	Homegarden	1260	1354	19,3
Hom5	Homegarden	1560	1497	17,6
Mai1	Maize field	1020	864	20,6
Mai2	Maize field	860	910	21,6
Mai3	Maize field	890	928	21,3
Mai4	Maize field	960	848	21,0
Mai5	Maize field	962	652	21,0
Sav1	Savanna	871	1063	21,5
Sav2	Savanna	912	1002	21,3
Sav3	Savanna	1130	811	20,0
Sav4	Savanna	993	616	20,8
Sav5	Savanna	950	609	21,0
Flm1	Forest lower mont.	1920	2653	15,5
Flm2	Forest lower mont.	1800	2073	16,2
Flm3	Forest lower mont.	1620	2020	17,2
Flm4	Forest lower mont.	1650	1867	17,0
Flm6	Forest lower mont.	2040	1956	14,8
Fpo1	*Podocarpus* forest	2850	1713	10,2
Fpo2	*Podocarpus* forest	2940	1301	9,6
Fpo3	*Podocarpus* forest	2970	1189	9,5
Fpo4	*Podocarpus* forest	2720	1434	10,9
Fpo5	*Podocarpus* forest	2800	1732	10,5
FPd1	*Podocarpus* disturbed	3060	1507	9,0
FPd2	*Podocarpus* disturbed	2990	1147	9,3
FPd3	*Podocarpus* disturbed	2880	1378	10,0
FPd4	*Podocarpus* disturbed	2820	1336	10,3
FPd5	*Podocarpus* disturbed	2770	1764	10,6
FOc1	*Ocotea* forest	2120	2519	14,3
FOc2	*Ocotea* forest	2260	2453	13,6
FOc3	*Ocotea* forest	2540	1928	11,9
FOC4	*Ocotea* forest	2650	1769	11,3
FOC5	*Ocotea* forest	2750	1539	10,8
FOd1	*Ocotea* disturbed	2220	2508	13,8
FOd2	*Ocotea* disturbed	2470	1528	12,3
FOd3	*Ocotea* disturbed	2270	1991	13,5
FOd4	*Ocotea* disturbed	2560	1926	11,9
FOd5	*Ocotea* disturbed	2370	2021	12,9
FEr0	*Erica trimera* forest	3910	960	4,2
FEr1	*Erica trimera* forest	3850	1020	4,5
FEr2	*Erica trimera* forest	3510	1128	6,5
FEr3	*Erica trimera* forest	3830	995	4,6
FEr4	*Erica trimera* forest	3500	1199	6,5
FEd1	*Erica trimera* forest dist.	3520	1120	6,3
FEd2	*Erica trimera* forest dist.	3720	735	5,2
FEd3	*Erica trimera* forest dist.	3940	565	3,9
FEd4	*Erica trimera* forest dist.	3660	660	5,6
FEd5	*Erica trimera* forest dist.	3800	610	4,8
Hel1	*Helichrysum*	3880	650	4,3
Hel2	*Helichrysum*	4190	862	2,5
Hel3	*Helichrysum*	4240	593	2,2
Hel4	*Helichrysum*	4390	772	1,3
Hel5	*Helichrysum*	4550	828	0,5

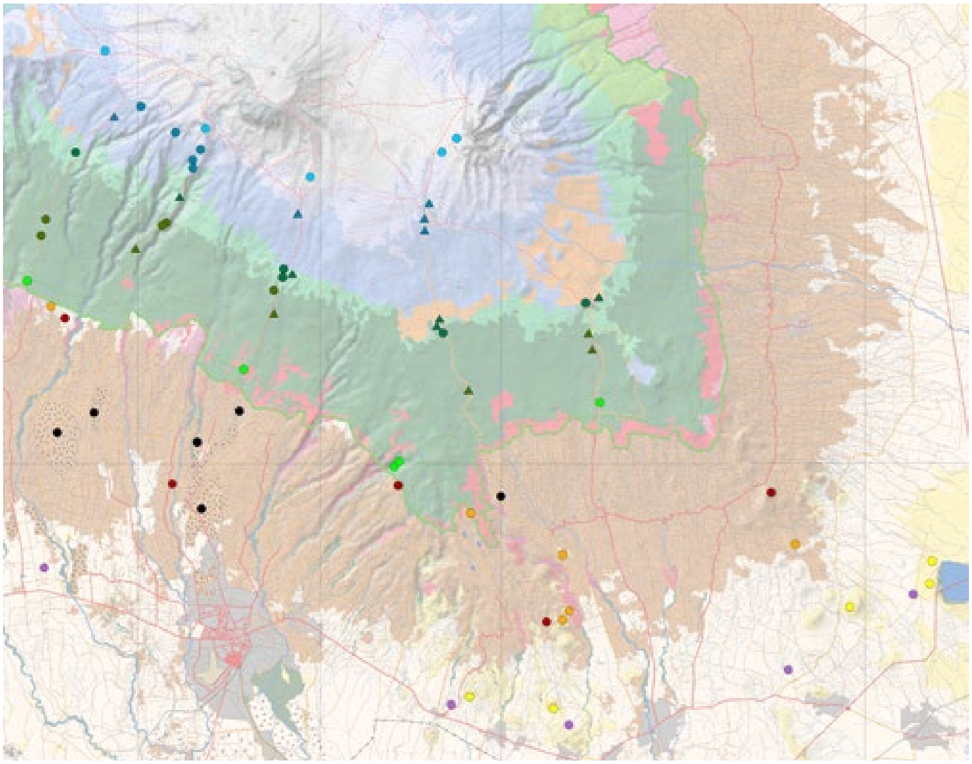


Fig. 2. Position of KiLi research plots on the mountain.

Fig. 3. Measuring and marking plots with the KiLi staff of the Central Project.

Figs. 4 & 5 (right and below right). Installation of climatic gadgets on one of the highest KiLi plots at 3900 m in *Erica trimera* forest.

Table 3: List of educated PhD, Master and Bachelor students 2010–2018

Name	SP	Nation.	Degree
Jonas Kuppler	SP 7	German	Dipl
Julian Fritsch	SP 7	German	Dipl
Richard Bleil	SP 7	German	Dipl
Moritz Katz	SP 7	German	Dipl
Julia Schmack	SP 6	German	MSc
Andreas Schweiger	SP 2	German	MSc
Bernd Berauer	SP 4	German	MSc
Christina Behler	SP 6	German	MSc
David Kienle	SP 2	German	MSc
Edda Lutta	SP 3	Tanzanian	MSc
Imani Kikoti	SP 3	Tanzanian	MSc
Joel Baumann	SP 4	Swiss	MSc
Johanna Häußler	SP 7	German	MSc
Salum Kulunge	SP 3	Tanzanian	MSc
Tatajana Schneider	SP 5	German	MSc
Alexander Neu	SP 6	German	MSc
Armin Komposch	SP 4	Swiss	MSc
Marcus Z.-Schlingm.	SP 3	German	MSc
Michael Haas	SP 7	German	MSc
Simon Schlauss	SP1/7	German	MSc
Ethan Oleson	SP 4	American	MSc
Lisa Ehrmanntraut	SP 6	German	MSc
Moritz Gaffke	SP 5	German	MSc
Samuel Massa	SP 4	Swiss	MSc
Sophia Hochrein	SP 7	German	MSc
Daniel-S. Moser	SP 2	German	MSc
Alice Claßen	SP 7	German	PhD
Andreas Enßlin	SP 4	German	PhD
Anna Kühnel	SP 2	German	PhD
Gemma Rutten	SP 4	Dutch	PhD
Giulia Zancolli	SP 7	Italian	PhD
Hamadi Dulle	SP 6	Tanzanian	PhD
Holger Pabst	SP 3	German	PhD
Lisa Schüler	SP 4	German	PhD
Maria Helbig	SP 6	German	PhD
Neduvotu Mollel	SP 4	Tanzanian	PhD
Rico Fischer	SP 5	German	PhD
Stefan Ferger	SP 6	German	PhD
William Kindeketa	SP 7	Tanzanian	PhD
Christine Ngereza	SP 7	Tanzanian	PhD
David Sch. Costa	SP 5	German	PhD
Ephraim Mwangomo	SP 1	Tanzanian	PhD
Friederike Gerschlauer	SP 3	German	PhD
Insa Otte	SP 1	German	PhD
Juliane Röder	SP 7	German	PhD
Thomas Leipold	SP 2	German	PhD
James Mnyonga	SP 2	Tanzanian	PhD
Lazaro Madadi	SP 2	Tanzanian	PhD
Young Eun Jung	SP 2	Korean	PhD
Adrian Gütlein	SP 3	German	PhD
Anna Vogeler	SP 6	German	PhD
Emanuel Ndossi	SP 3	Tanzanian	PhD
Florian Detsch	SP 1	German	PhD
Friederike Gebert	SP 7	German	PhD
Hawa Mushi	SP 5	Tanzanian	PhD
Henry Njovu	SP 7	Tanzanian	PhD
Jerome Kimaro	SP 2	Tanzanian	PhD
Joscha Becker	SP 3	German	PhD
Marion Renner	SP 4	German	PhD
Maximilian Vollstaedt	SP 6	German	PhD
Natalia Sierra Cornejo	SP 2	Spanish	PhD
Sara Frederiksen	SP 7	Danish	PhD
Emmanuel Lyimo	SP 6	Tanzanian	PhD
Hannes Oeverdieck	SP 2	German	PhD
Wilbert Simbila	SP 1	Tanzanian	PhD
Antonia Mayr	SP 7	German	PhD
Vincent Montade	AP1	French	PostD
Ulla Kaasalainen	SP4	Finnish	PostD

Fig. 6. Students of KiLi phase 2.

Fig. 7 (left above). Tanzanian KiLi PhD students Christine Ngereza (National Museums Dar es Salaam), Neduvoto Mollel (TPRI, Arusha), Beatrice Mmary (assistant coordinator) and William Kindeketa (COSTECH) during an excursion to Lake Chala, East Kilimanjaro.

Fig. 8 (above right). KiLi PhD students Anna Vogeler (University of Ulm), Hawa Mushi (University of Oldenburg) and Natalia Sierra-Cornejo (University of Göttingen).

Fig. 9. (below left). KiLi students, staff and guests during the evaluation meeting in Frankfurt, June 2016 (from left to right: Alexander Neu, Beatrice Mmary, Catherine Masao, Jerome Kimaro, Hawa Mushi, Emanuel Ndossi, Henry Njovu and Hamadi Dulle in front).

Fig. 10. (below right) KiLi PhD student Ephraim Mwangomo explains climate installments at plot Mai5.

Fig. 11. Part of the KiLi staff 2013 – drivers, house maids, watchmen and field assistants. From left to right: hind row: Judica Malisa (matron Kidia), field assistants Ombeni Mushi, George, Raymond Sway and Amini Mmary, watchman Elisaria Temba, field assistant Ayubu Mtaturu, PhD student Holger Pabst, drivers Alexander Mmary, Godfrey Ringo and August Temu. Second row: driver Nelson Masam, field assistants Ramson Mmary and David Mungure, house maid and scientific garden helper Julieth Mshida, field assistants Jimmy Ndyamakama and Mgeta Kaswamila, driver Wilbard Lyatuu, house maids Rafiki Mtaturu and Fortunata. First row: field assistant Zacharia Maromboso, day watchman and gardener Dastan Chaki, field assistant Jumanne Mwinyi, assistant coordinator Beatrice Mmary, coordinator Claudia Hemp and field assistant James Ndimion.

Figs. 12 & 13. KiLi vehicles at the scientific station Nkweseko (left) and CP1 team during forest inventory (right).

Plot owner

The research plots of the KiLi Project were chosen in agreement with around 30 plot owners, 6 commercial coffee plantations and with the Kilimanjaro National Park. The lowest plot was a savanna woodland at 860 m, the highest plot a *Helichrysum* scrub at 4550 m. Especially without the support of the private plot owners, the managers of the commercial coffee plantations and Kilimanjaro National Park authorities research would not have been possible. Students and technicians of the KiLi Project were allowed to access the plots under ongoing agricultural use at any time and stage of harvest and even at night. So we would like to express our sincere thanks to all supporting our team!

Fig. 14 (above). Plot owner Mzee Salimu Akaro and his family of Sav1, Uchira and **Fig. 15** (below) plot owner Stephen Atoni savanna woodland Mabungu Hill, Sav3 (left) and Chrispin Phillip of maize field Mai5, Chala area (right).

Fig. 16 (above). Plot owner homegarden Hom3, Bibi Mushi & family and **Fig. 17 & 18** (below) Betty Mmary signing plot rent agreement with plot owner Edward Machange of maize field Mai4.

Fig. 19 (above). Plot owner Firimini Luka Masaae and wife of Chagga homegarden Hom5, East Kilimanjaro and **Fig. 20 & 21** (below) Plot owner Abel Hipolity of the montane grassland Gra6 (right middle) and Evarist Daniel Mbuya of grassland Gra4, Kirua (below right).

Fig. 22 & 23. Plot owner Fidelis Marika & family, grassland Gra5.

Fig. 24 (below) Mama Johanna Laurenti of homegarden Hom2 preparing to brew banana beer.

Central database of the KiLiProject

by Jie Zhang

For a joint project across different disciplines, successful data management throughout its life cycle is essential for meta-analysis and synthesis. Therefore, the KiLi Project implemented a central database to ensure the long-term data storage with standardized metadata, the regulated and documented data exchange, as well as the data integration and synthesis. Activities such as metadata documentation, data upload, data request, data download, data merging, data aggregation, and data visualization are carried out online via the web interface of the database (KiLi homepage, *www.kilimanjaro.biozentrum.uni-wuerzburg.de*). The KiLi homepage serves also as a communication platform to facilitate station booking, permit application, event notification, document sharing, and forum discussions. A WebGIS platform was also developed in the KiLi homepage for interactive geo-visualization. In the last two phases of the project, more than 200 dataset inputs and more than 1500 data exchanges took place in the KiLi database.

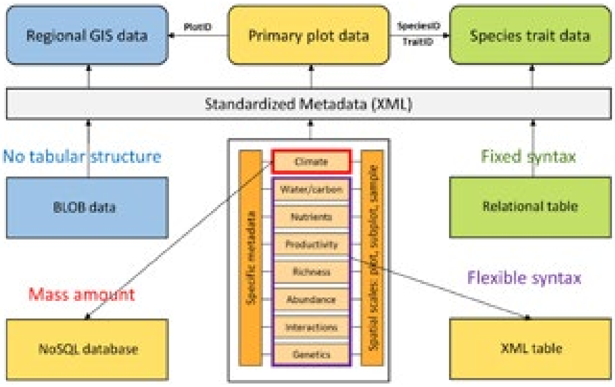


Fig. 1. General structure of KiLi central database.

Temperature as a driver of biodiversity

by Marcell Peters et al.

The diversity of plants and animals in Earth's arctic regions is moderate. Tropical latitudes in contrast are teeming with different species where new organisms are being discovered all the time. Why is the diversity of animals and plants so unevenly distributed on our planet? We tried to find answers to this question on Mt Kilimanjaro by analysing the largest data set on plant and animal diversity which was ever compiled along a broad climatic gradient. This data set was collected by a large number of Tanzanian and German researchers of the KiLi Project who were experts for groups like plants, birds, grasshoppers, spiders, dung beetles and many others. We tested several different hypotheses which are considered of prime importance when it comes explaining the variation in species diversity on earth. One hypothesis, for instance, is that the primary productivity of a habitat is ultimately decisive for the number of species living there. Simply put: "A larger cake can sustain more species than a small one". Another hypothesis assumes that the rates of evolution and speciation depend on temperature. According to this assumption, more species thrive in a warmer climate than in a cold one. So far, these hypotheses have been examined usually by focusing on selected groups of species, like ants or birds. With the data set collected by the KiLi Project we were for the first time able to compare among different groups of organisms how the diversity changes along an extreme climatic gradient. The study revealed that biodiversity in communities is mainly determined by temperature. The warmer it is, the greater the diversity. The more groups of animals and plants were investigated in parallel, the greater was the significance of temperature for explaining biodiversity, whereas the importance of all other variables decreased accordingly. We believe that this is strong evidence supporting the assumption that temperature is actually more decisive for distribution patterns of overall biodiversity than productivity or size of habitats.

Subproject 1

Ecological climatology and remote sensing

With respect to the importance of the atmospheric water budget for the Kilimanjaro ecosystem and the mutual potential feedbacks between climate and ecosystem change, this project focused on the remote sensing supported analysis of the state and change of ecoclimatological dynamics as a function of ecosystem disturbances along the elevational gradient from the savanna to the *Helichrysum* zone.

Climate characteristics and dynamics in the Kilimanjaro region are mainly determined by (i) global climate and (ii) local land-cover change. Both processes affect the local-scale climate which in turn is a key parameter for ecosystem processes and biodiversity. Changes in the local hydrological cycle will likely have the most serious or beneficial consequences for the region, and the hydrological cycle is linked to the carbon cycle through the water use efficiency.

CLIMATE PARAMETERS

Eco-meteorological characteristics of the southern slopes of Kilimanjaro, Tanzania

by Tim Appelhans, Ephraim Mwangomo, Insa Otte, Florian Detsch, Thomas Nauss & Andreas Hemp

We implemented the set-up of a new meteorological station network on the southern slopes of Kilimanjaro, Tanzania. The installation of this network started in 2010 and covered an elevational gradient which ranged from the savanna to the *Helichrysum* zone. We recorded the characteristics of air temperature, air humidity and precipitation in both a plot-based and area-wide perspective. The station set-up followed a hierarchical approach covering an elevational as well as a land-use disturbance gradient. It consisted of approximately 60 basic stations measuring ambient air temperature and above-ground air humidity and 11 precipitation measurement sites. All data was recorded automatically every 5 minutes. The data loggers were placed inside white-painted funnels so that the sensor was pointing downward ensuring both shielding from direct sunlight, as well as sufficient ventilation. The recorded data was collected manually by a local field assistant roughly every 4 weeks for each research site.

Ambient air temperature is an important parameter of ecosystem functioning, as it is tightly linked to the level of available energy within a certain system. Spatial patterns of ambient air temperature play a major role in controlling species distribution of certain organisms which makes area-wide data indispensable for spatial ecological analyses

Fig. 1. An example of the standard set-up of the basic stations, which measures air-temperature and relative humidity. Standard household funnels with white automotive spray paint coating are used for radiation shielding (Photo: Tim Appelhans).

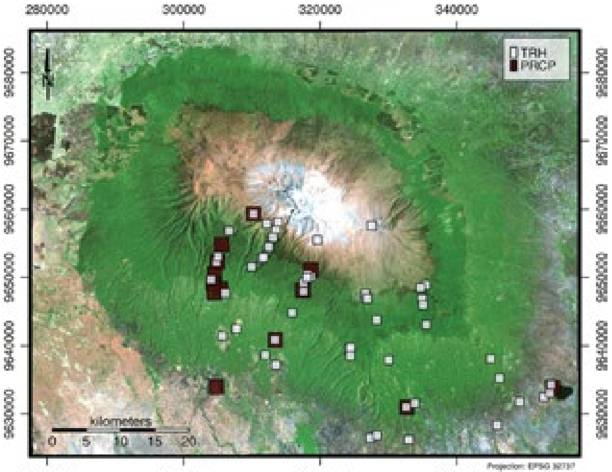


Fig. 2. Overview of the spatial distribution of the basic (TRH: red) and extended (PRCP: blue) stations at Kilimanjaro.

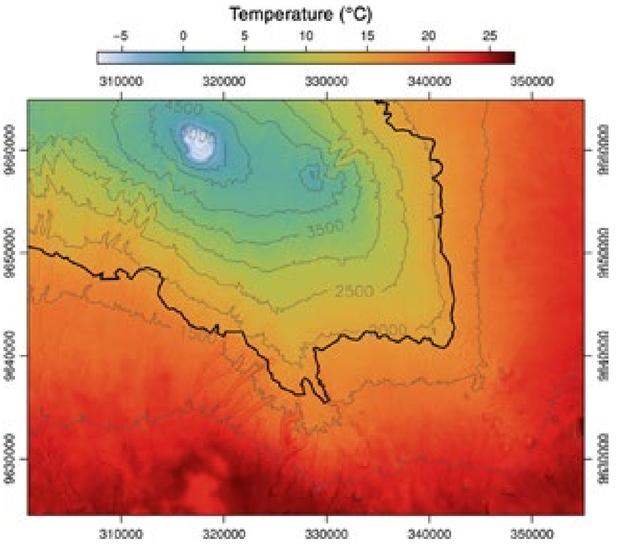


Fig. 3. Mean annual temperature map between 2011 and 2014. The black line denotes the current national park border. Grey lines are elevation contour lines.

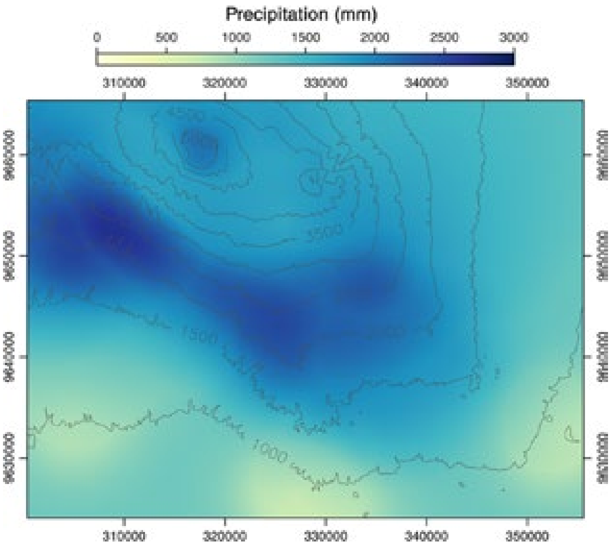


Fig. 4. Precipitation map between 2011 and 2014. Grey lines are elevation contour lines.

such as species distribution modelling. Mean annual air temperature for the southern slopes of Kilimanjaro between 2011 and 2014 ranged from about 25 °C in the surrounding savanna to about −8 °C at the summit and generally depicted a linear decrease of temperature with elevation (see Fig. 3). Considering mean annual relative humidity data, which was sampled between 2011 and 2014, the moist forest belt was clearly visible exhibiting sharp edges towards the areas above and below (see Fig. 5). These areas were significantly drier with the driest areas found in the savanna and agricultural lowlands surrounding Kilimanjaro. With regard to atmospheric water availability, precipitation was generally the most important input parameter. The maximum precipitation was observed in an elevation of 2300 m a. s. l. Furthermore, we provided high resolution maps of mean monthly and mean annual temperature, humidity and precipitation for Kilimanjaro based on our ground-based measurements, which can be used for geographically oriented meteorological or ecological investigations.

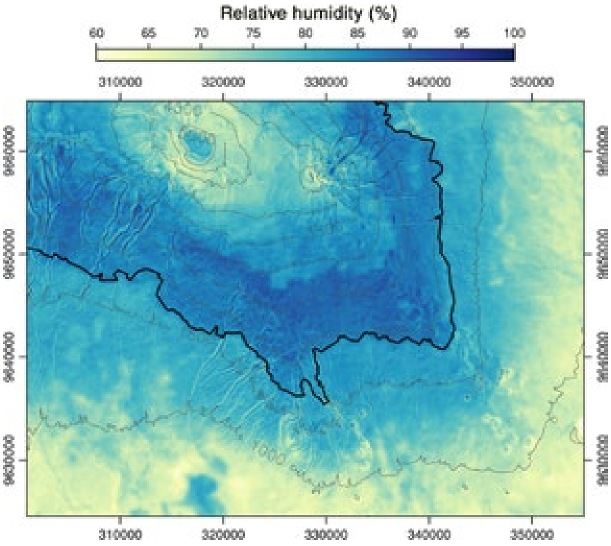


Fig. 5. Relative humidity map between 2011 and 2014. The black line denotes the current national park border. Grey lines are elevation contour lines.

Point observations allow for investigation and formulation of processes that relate biotic and abiotic ecosystem components of the system, while area-wide data sets are able to provide a geographic perspective enabling inference of the locally identified processes to a larger, regional extent.

Citation: Appelhans T, Mwangomo E, Otte I, Detsch F, Nauss T, Hemp A (2015) Eco-meteorological characteristics of the southern slopes of Kilimanjaro, Tanzania. International Journal of Climatology 36: 3245–3258. doi: 10.1002/joc.4552

TEMPERATURE

Interpolation of monthly air temperature at Mt Kilimanjaro, Tanzania

by Tim Appelhans, Ephraim Mwangomo, Douglas R. Hardy, Andreas Hemp & Thomas Nauss

For biodiversity and ecosystem research, climate conditions are a major explanatory variable, and a common demand of biodiversity researchers is to get plot-scale information on the weather and climate conditions. So basically, the question to be addressed was how we could provide accurate weather status information for biodiversity and ecosystem research which often demands site specific information for certain intensively investigated research plots and area-wide information on a landscape scale. In order to scale the generally ground based plot-based research findings to a landscape level and provide maps of air temperature, spatial interpolation methods of meteorological variables are required. Based on a network of temperature observation plots across the southern slopes of Mt Kilimanjaro, different machine learning algorithms were tested to predict spatial temperature patterns. As a result, detailed air-temperature maps could be derived.

Citation: Appelhans T, Mwangomo E, Hardy D-R, Hemp A, Nauss T (2015) Evaluating machine learning approaches for the interpolation of monthly air temperature at Mt Kilimanjaro, Tanzania. Spatial Statistics 14, Part A: 91–113. doi: 10.1016/j.spasta.2015.05.008

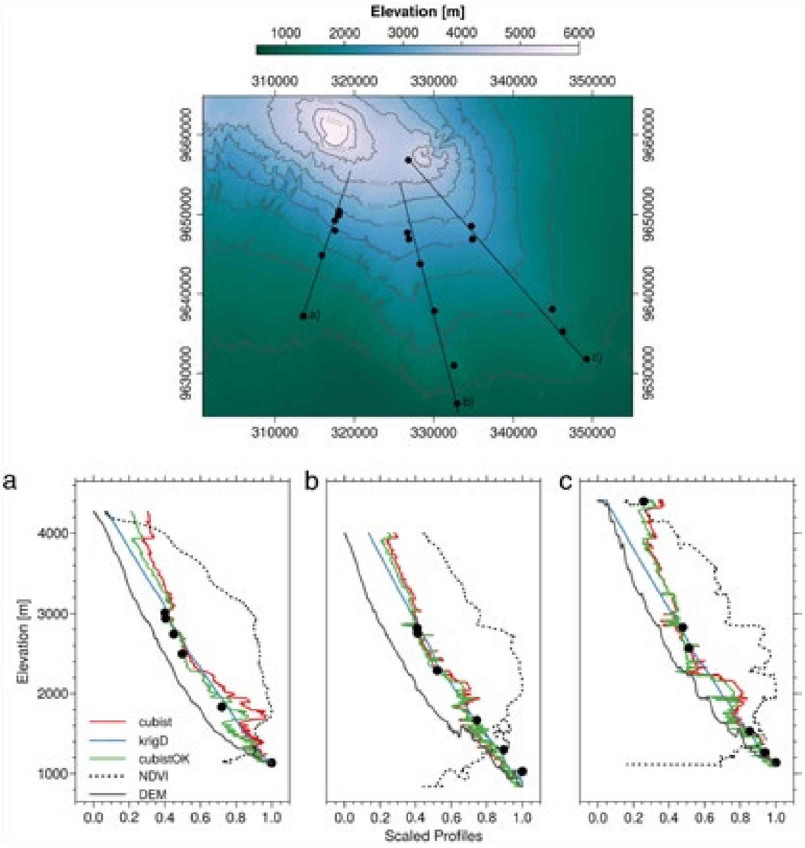


Fig. 1. Profiles of the predicted mean annual air temperature for 2014 along (a) Mweka, (b) Maua and (c) Marangu route based on cubist (red) and kriging with elevation as external drift (blue).

PRECIPITATION

Observations of long-term trends and seasonal variability of rainfall at lowland stations

by Insa Otte, Florian Detsch, Ephraim Mwangomo, Andreas Hemp, Tim Appelhans & Thomas Nauss

Future rainfall dynamics in the Kilimanjaro region will mainly be influenced by both global climate and local land-cover change. The dense forest belt in low and mid elevations at Mt Kilimanjaro provides not only water for the major river systems, but is also a resource for agriculture along the densely populated southern slopes, and a home for a vast variety of endemic species. Therefore, the variation of rainfall dynamics was of particular interest. Although an increase in rainfall is expected, also rising temperatures are predicted for the Kilimanjaro region.

We analyzed in-situ rainfall of five rainfall stations to get insights into seasonal variability and multi-decadal trends in the lowlands and lower elevations of the Kilimanjaro region. Therefore, we used monthly rainfall totals from two stations of the Tanzanian Meteorological Agency, namely Moshi and Kilimanjaro Airport (KIA). Additionally, we got the precipitation data from two mission stations (Kilema and Kibosho) and from the sugar cane plantation TPC (Fig. 1). The datasets of the two missions covered a time span of 74 and 72 years, starting in 1940 and 1942, while rainfall data obtained from the Tanzanian Meteorological Agency and from the sugar cane plantation started in 1973 and 1974 and thus covered 40–41 years. Our results revealed that seasonality has changed especially during the long rains between March and May. The long rains got drier in recent years, while the short rains showed the tendency to get more abundant and to start approximately one month later, with highest rainfall amounts during December.

We also investigated the influence of the oceans on rainfall dynamics in the Kilimanjaro region. For this analysis, we used the El Niño-Southern Oscillation (ENSO) as a proxy for the Pacific Ocean and the Indian Ocean Dipole (IOD) for the Indian Ocean. If ENSO and IOD occurred simultaneously, rainfall amounts were enhanced. During La Niña years, rainfall increased in the following year, while during the onset year rainfall patterns were more diverse. Positive IOD led to enhanced rainfall amounts. Although both rainy seasons were altered by ENSO and IOD, the short rains were more variable (Fig. 4).

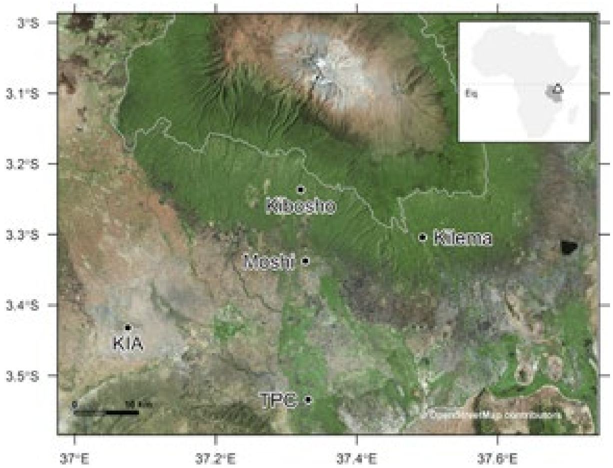


Fig. 1. Overview of the study area including two stations of the Tanzanian Meteorological Agency at KIA and Moshi, two mission stations (Kilema and Kibosho), and one sugar cane plantation (TPC), which are used for long-term time series analysis of rainfall.

Citation: Otte I, Detsch F, Mwangomo E, Hemp A, Appelhans T, Nauss T (2017) Multidecadal trends and interannual variability of rainfall as observed from five lowland stations at Mt Kilimanjaro, Tanzania. Journal of Hydrometeorology 18: 349–361. doi: 10.1175/JHM-D-16-0062.1

Fig. 2 & 3. PhD student of SP 1, Ephraim Mwangomo (left), explaining installations to measure climatic data to a group of scientists (right).

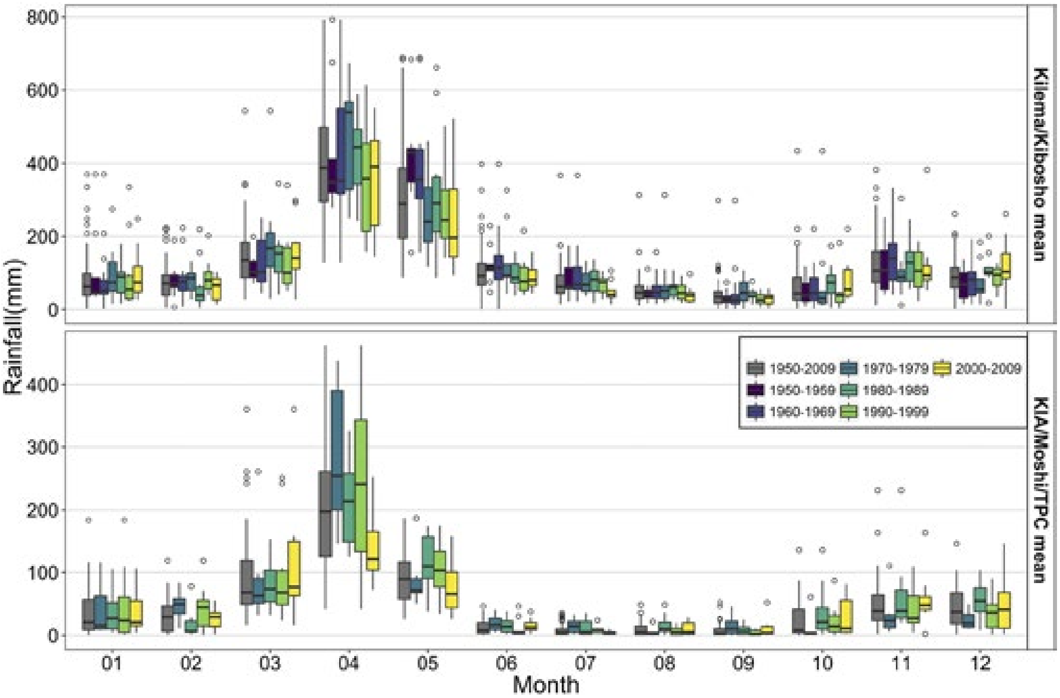


Fig. 4. Long-term monthly mean rainfall averaged over the stations (top) Kilema and Kibosho (1950–2009) and (bottom) KIA, Moshi, and TPC (1974–2009) for each decade. The overall mean for the entire time span is displayed in the grey boxplot (solid horizontal line shows the median and circles are outliers).

Seasonality of atmospheric water input at the southern slopes of Mt Kilimanjaro

by Insa Otte, Florian Detsch, Adrian Gütlein, Martha Scholl, Ralf Kiese, Tim Appelhans & Thomas Nauss

Understanding the driving factors of atmospheric water input is particularly important in densely populated regions of the southern slopes of Mt Kilimanjaro with the mountain functioning as a water tower supplying crucial amounts of water for domestic and agricultural uses. Besides rainfall, precipitation in montane forests also includes throughfall and fog. Throughfall is defined as precipitation sampled under the vegetation canopy and consists of both, rainfall and fog at this site. We collected weekly samples of rainfall, throughfall and fog along the Machame route (Fig. 1 and 2) as well as at one savanna and one homegarden site along an elevation transect ranging from 950 m a.s.l. to 3880 m a.s.l. For a better understanding of the moisture regime and to detect the source regions of atmospheric moisture, we used (i) stable isotopes of precipitation as a hydrological tracer and (ii) HYSPLIT backward trajectories.

Our results show, that two different moisture sources contributed to the precipitation in the research area: (i) local moisture recycling and (ii) regional moisture sources. The general precipitation seasonality followed the bimodal rainfall distribution under the influences of south- and northeasterly trade winds (Fig. 3). Seasonality of isotope values showed, that the densely forested slopes of Kilimanjaro enhanced moisture recycling after the onset of the rainy seasons.

Citation: Otte I, Detsch F, Gütlein A, Scholl M, Kiese R, Appelhans T, Nauss T (2017) Seasonality of stable isotope composition of atmospheric water input at the southern slopes of Mt Kilimanjaro, Tanzania. Hydrological Processes 31: 3932–3947. doi:10.1002/hyp.11311

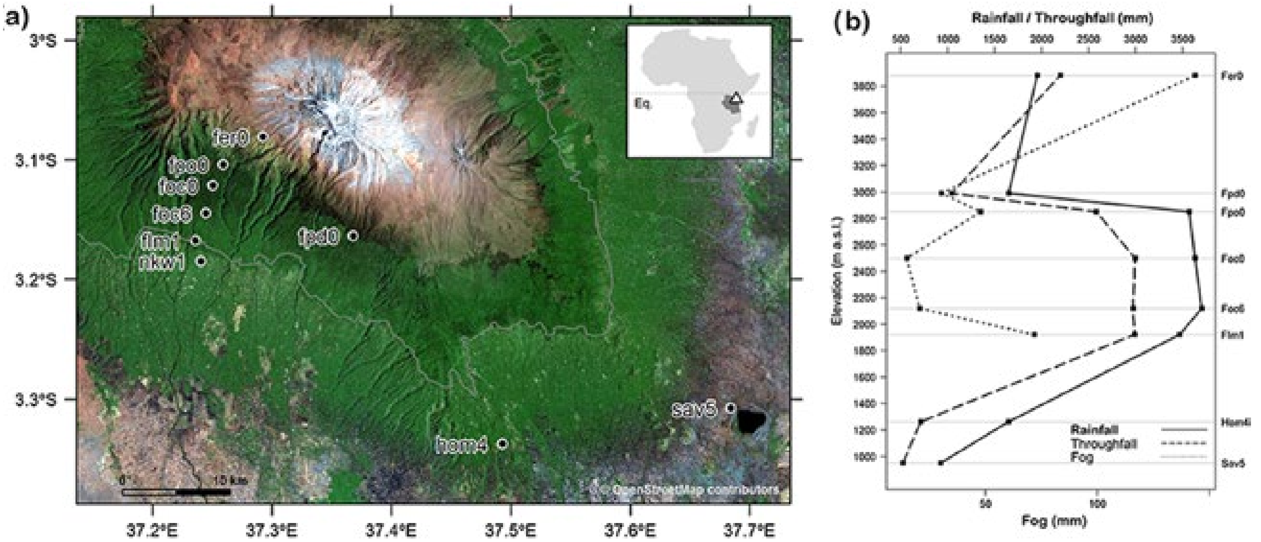


Fig. 1. (a) Sampling sites in the research area including the location of the study area within the African continent. (b) Annual rainfall, throughfall, and fog amounts along the elevation transect in the research area.

Fig. 2. Measurement devices for quantification of fog, throughfall and rainfall.

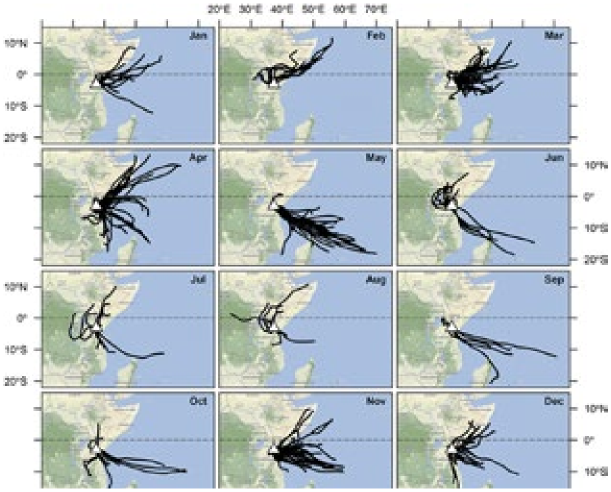


Fig. 3. 96-hour HYSPLIT backward trajectories based on the National Centers for Environmental Prediction and National Center for Atmospheric Research reanalysis data calculated for every precipitation measurement.

EVAPOTRANSPIRATION

A glimpse at short-term controls of evapotranspiration along the southern slopes of Kilimanjaro

by Florian Detsch, Insa Otte, Tim Appelhans & Thomas Nauss

Land-use change influences the local to regional-scale water balance. Water input is determined by precipitation, while surface run-off, ground-water flow, evaporation, and transpiration are responsible for the water output. E.g., deforestation causes decreased evapotranspiration (ET) and higher surface temperatures. At the southern slopes of Kilimanjaro, local land-use change and global climate change are most important for future climate characteristics. Based on measurements with a scintillometer (Fig. 1b), we derived evapotranspiration (ET) rates covering seven distinct habitat types from savanna woodlands to the upper mountain *Helichrysum* zone (940 to 3960 m a.s.l).

Along the elevational gradient (Fig. 1a) ET showed a hump-shape which was strongly linked to the net radiation budget at each elevation level. Topography and high cloud/fog frequencies influenced ET at higher elevations, while moisture limitations caused low ET rates at the low-lying savanna woodlands. Consequently, the highest ET amounts occurred at the submontane coffee/grassland level where neither moisture nor energy limitations could be identified (Fig. 2).

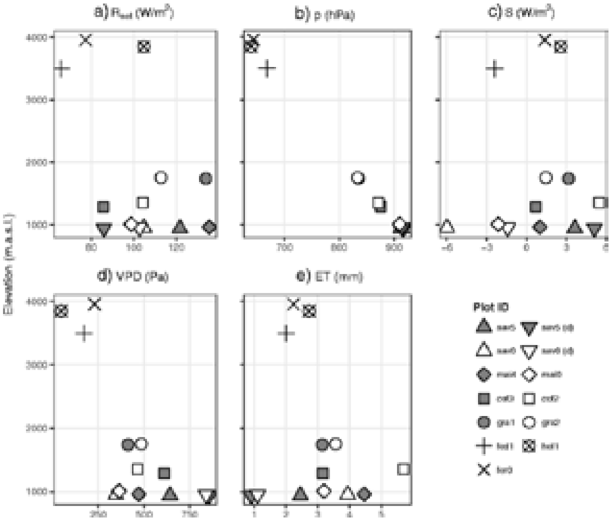
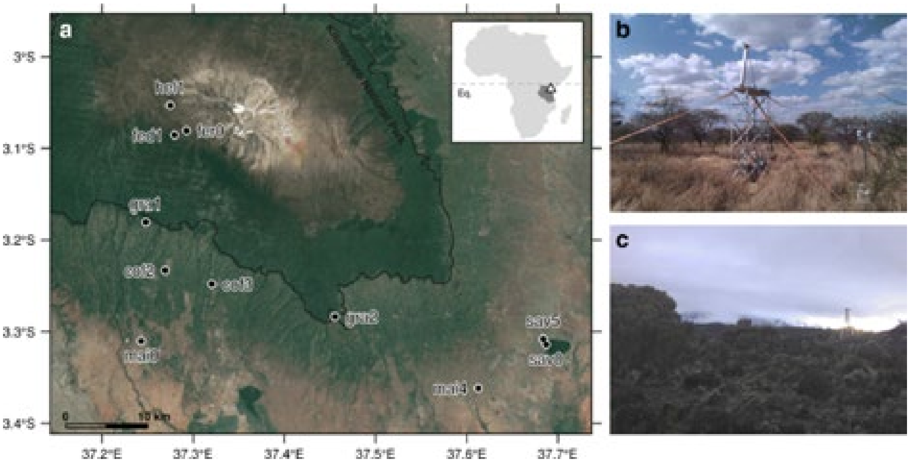


Fig. 2. Elevation profiles of mean daily a) net radiation (Rnet), b) air pressure (p), c) soil heat flux (S), d) vapor pressure deficit (VPD), and e) evapotranspiration (ET). In the legend, "(d)" indicates dry-season measurements, and point shapes and fill colours signify different land covers and plots per land cover, respectively.



Citation: Detsch F, Otte I, Appelhans T, Nauss T (2017) A glimpse at short-term controls of evapotranspiration along the southern slopes of Kilimanjaro. Environmental Monitoring and Assessment 189: 465. doi:10.1007/s10661-017-6179-9.

Fig. 1. Location of Kilimanjaro (top-right panel) and sampling plots superimposed upon a satellite image of the study area (EPSG:4326; Google and TerraMetrics (2017)). b, c Impressions from the field campaign at dry-season Sav5 and Hel1, respectively.

REMOTE SENSING

In-situ observations of eco-meteorological parameters provide valuable insights for ecological research, but their area-wide significance, even for a small local domain is limited. To overcome these limitations, remote sensing can be used.

Spatial patterns of sea surface temperature influences on east African precipitation

by Tim Appelhans & Thomas Nauss

East Africa is characterized by a rather dry annual precipitation climatology with two distinct rainy seasons. The modulation of these rainy seasons by regional to global sea surface temperature (SST) anomalies has been the focus of numerous studies in the past. From these studies it became evident that, at least for the "short rains," the Indian Ocean Dipole (IOD) played a much bigger role than the El Nino Southern Oscillation (ENSO) in East Africa.

In order to investigate sea surface temperature driven precipitation anomalies for the region we used the algorithm of empirical orthogonal teleconnection (EOT) analysis as a data mining tool. We investigated the entire East African domain and 5 smaller sub-regions mainly located in areas of mountainous terrain (Fig. 1). The potential SST driven precipitation anomalies were analyzed for (i) the time interval between 1982 and 2010 and (ii) for several sub-regions of about 100 × 100 km in addition to the entire East African domain. In searching for influential sea surface temperature patterns we did not focus on any particular season or oceanic region, but investigated different time lags from 0 to 12 months. The strongest influence was identified for the non-lagged influences of the Indian Ocean in close vicinity to the East African coast (Fig. 4).

Citation: Appelhans T, Nauss T, (2016) Spatial patterns of sea surface temperature influences on East African precipitation as revealed by empirical orthogonal teleconnections. Atmospheric Science 4: 3. doi: 10.3389/feart.2016.00003

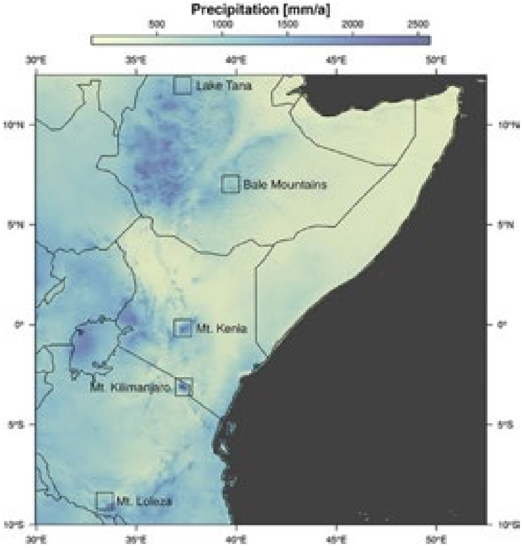


Fig. 1. Mean annual precipitation between 1982 and 2010 in the response domains. Black squares show the locations of the small response domains.

Fig 2 & 3. PhD students of SP1, Insa Otte (left) and Florian Detsch (right).

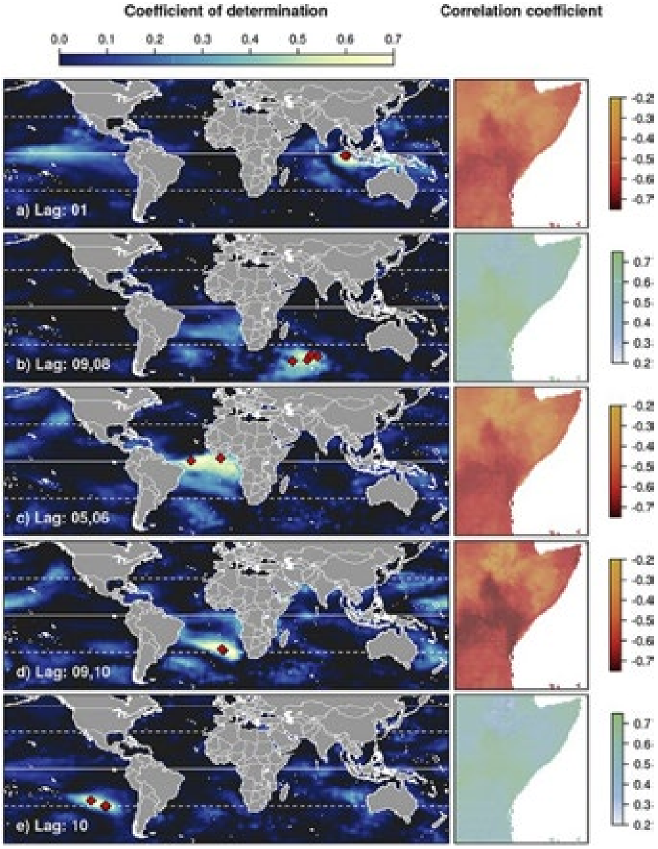


Fig. 4. The five most important SST regions for the East African domain. Left panels show mean coefficient of determination between each pixel of the predictor domain and the respective base points (red diamonds). Right panels show average correlation coefficient between each pixel in the response domain and the respective base points. Lag times are provided in the lower left corner of the left panels.

Seasonal and long-term vegetation dynamics from 1-km GIMMS-based DVI time series at Mt Kilimanjaro, Tanzania

by Florian Detsch, Insa Otte, Tim Appelhans, Andreas Hemp & Thomas Nauss

Vegetation dynamics in the Kilimanjaro region are affected by (i) global climate change and (ii) local land-cover change resulting from natural or anthropogenic disturbance. Effects of land-use change on the local water budget and availability, as well as on vegetation response are much more diverse. Here we present long-term and seasonal vegetation dynamics based on a GIMMS-based NDVI record that was resampled to 1 km spatial resolution and covering a 30-year period (1982–2011).

Long-term trends showed for most areas above 3000 m a.s.l. increasing (greening) NDVI trends, which was mainly attributed to vegetation recovery after disastrous fires during the outgoing 20th century. But along the western mountain side, a strong decrease resulted as a consequence of fire-driven downward migration of *Erica* bush along the upper slopes and massive land conversion processes affecting the lower slopes (Fig. 1).

Regarding seasonality, a strong dependence of the regional vegetation on the effects of ENSO/IOD teleconnections became evident. Similar to previous findings on rainfall, the most beneficial effects occurred during concurrent El Niño/IOD events, while the impacts of La Niña were far less pronounced (Fig. 2). To sum up, the newly created 1-km NDVI record proved capable of capturing long-term and seasonal vegetation patterns, which particularly applies to large-scale teleconnections, and thus provides an invaluable archive of decadal-scale vegetation dynamics in the study area.

Citation: Detsch F, Otte I, Appelhans T, Hemp A, Nauss T, (2016) Seasonal and long-term vegetation dynamics from 1-km GIMMS-based NDVI time series at Mt Kilimanjaro, Tanzania. Remote Sensing of Environment 178: 70–83. doi: 10.1016/j.rse.2016.03.007

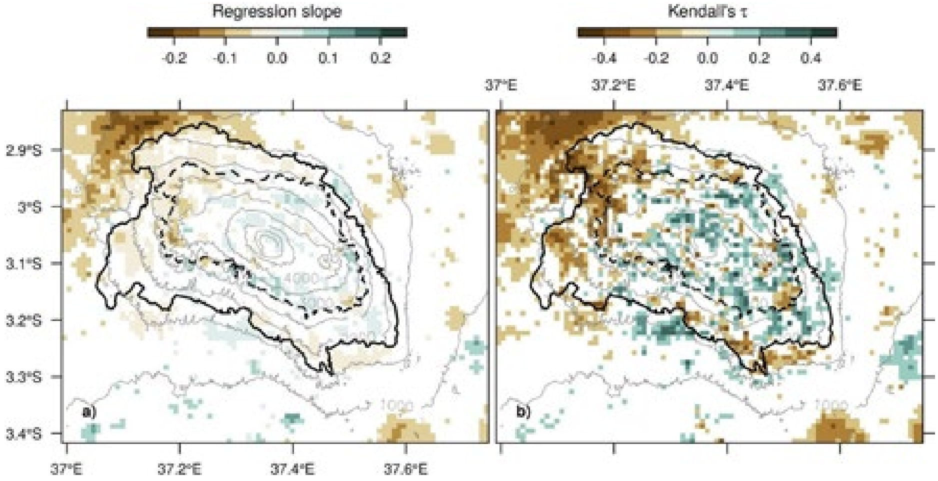


Fig. 1. a) Linear regression slope (only slopes larger than the corresponding RMSE are shown) and b) Kendall's τ ($p < 0.001$) calculated from monthly NDVIEOT between 1982 and 2011. Included are the old (black dashed; 1973–2005) and recent KINAPA boundaries (black solid; since 2005).

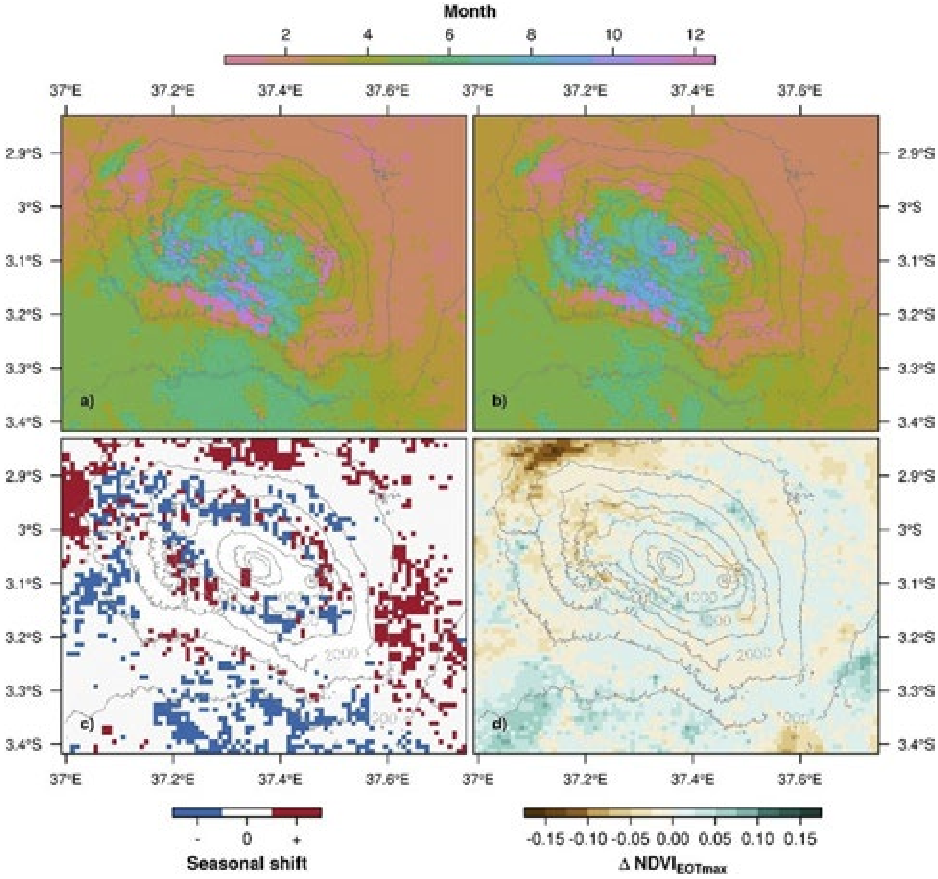


Fig. 2. a) Month with maximum vegetation activity estimated from peak NDVIEOT (NDVIEOTmax) from 1982 to 1991 and b) 2002 to 2011, c) resulting seasonal phase shifts ('–' means an earlier, '+' a later occurrence of NDVIEOTmax), and d) seasonal amplitude change of NDVIEOTmax (ΔNDVIEOTmax).

Subproject 2

Patterns in water flux and carbon cycle controls along land-use and climate gradients

The hidden part of Mount Kilimanjaro: fine root biomass and production

by Natalia Sierra Cornejo, Christoph Leuschner & Dietrich Hertel

Tropical forest ecosystems are highly productive, storing 40–50% of the carbon in terrestrial ecosystems. Fine root production represents an important contribution to these high values, as they account for 30–50% of net primary production in forest ecosystems, even if they only represent a small amount of the total plant biomass. They play a key role on the carbon cycle of this ecosystem as they present a rapid growth and turnover. Not only carbon stored to the roots, but also the release of carbon from roots to the soil through root decomposition is an important pathway of this cycle. Therefore, fine roots have a large influence on the ecosystem carbon fluxes, being crucial to include this data in this kind of studies.

But how do we define fine roots and what are their ecological functions? Fine roots are the ones responsible for water and nutrient acquisition. Traditionally, a diameter-based cut off has been established to assume that roots with a diameter equal or lower than 2 mm hold this function (nonetheless, there are also, to a much lesser extent, roots with bigger diameter able to take up nutrients). Other main ecological functions of fine roots are the association with symbionts and carbon exudation. One association with symbionts refers to the formation of mycorrhiza, which provides the plant with nitrogen, a higher absorption surface and defense mechanisms. On the other hand, the release of exudates alters the environment around the roots affecting their absorption capacity and provides a food source to the microbes in the surroundings. They also constitute a way of communication between the plant and the microbes, maintaining and supporting their diversity and developing an important role in plant defense.

Fig. 1. Roots from *Helichrysum* sp.

Mountain ecosystems offer a unique opportunity to study climate effects on different ecosystem components. Fine root biomass in forest ecosystems varies with different climatic factors such as air temperature and precipitation, edaphic factors such as pH and C:N ratio, as well as with stand characteristics, as aboveground biomass and basal area. On tropical montane forests, these factors change as we go upwards the mountain. The air temperature decreases and, therefore, the microbial activity is lower, resulting in slower decomposition and mineralization rates at higher elevations. The pH and C:N ratio in the soil increases with elevation, which leads to a situation of low nutrient availability. At the same time, the transport of compounds through the plasma membrane of the root cells is less active, since it is temperature sensitive. The set of these conditions at higher elevations leads to nutrient limitation conditions plants have to cope with. One possible solution to face this situation is to invest more biomass to the root system to be able to reach the nutrient patches and to acquire these resources. In fact, studies on tropical mountains in the Andes in South America have found a shift of the carbon allocation from the above parts of the plants to the roots, highlighting the importance of the root system at higher elevations. On the other side, referring to land-use change, it affects forest structure and species composition, presenting important consequences for carbon pools. Some studies have shown that there is an acceleration of the nutrient cycle due to the use of fertilizers as well as a decrease of fine root biomass with land-use intensity.

With our study we aimed to address the following questions: how is fine root biomass, necromass and production affected by the elevational gradient and the environmental and stand structure factors that change with it? Is there a shift of carbon allocation from the aboveground parts of the plants to the root system along the elevation? How does fine root biomass and necromass respond to land-use change?

To our knowledge, fine root related variables along elevational gradients in tropical regions have only been studied in Borneo and in the Ecuadorian and Peruvian Andes. Therefore, this is the first study on fine roots along an elevational gradient in Africa.

How did we develop our study?

We studied the southern slopes of Mt Kilimanjaro along an elevational gradient (871–4550 m a.s.l.) and a land-use gradient. We worked in all natural and disturbed habitats represented in the 65 plots established in five transects along the mountain in the framework of the KiLi Project. We realized a bio-necromass inventory taking random soil cores 3.5 cm in diameter down to 40 cm depth in each plot and separating living and dead tree roots under the stereoscope. Afterwards, we scanned the living roots and analyzed their morphological traits such as root length, average diameter and volume with the software WinRihizo Reg 2013 (Regent Instruments Inc. Québec, Canada). These are interesting root properties for studying the adaptation strategies of the plants to the different habitats. Finally, we dried the root samples and weighed them to obtain the data for fine root bio-and necromass per habitat.

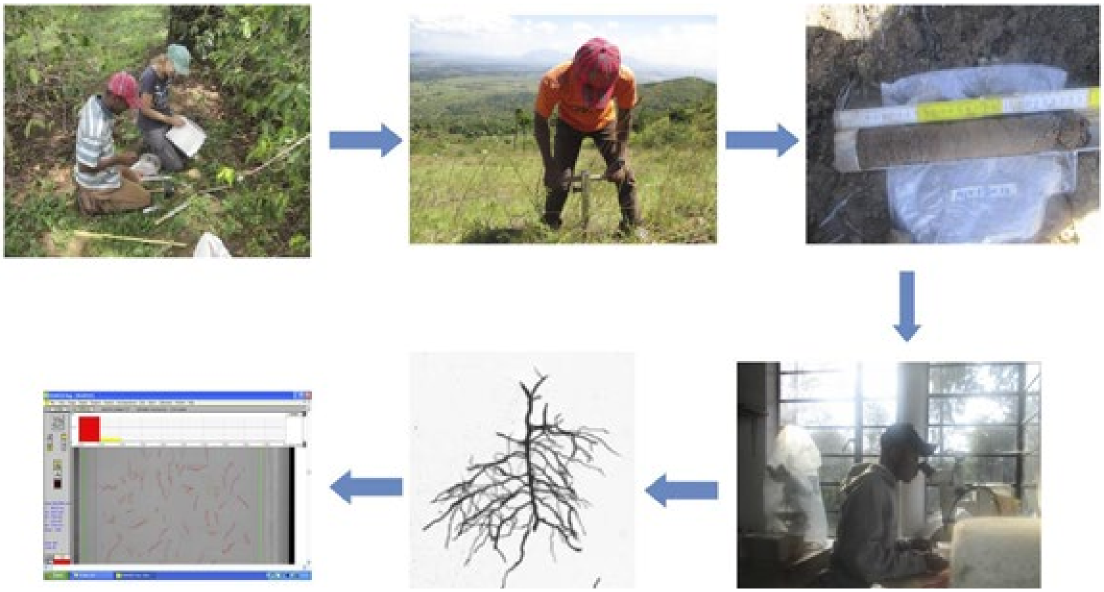


Fig. 2. Steps of the field and laboratory work. First we sampled the soil cores and took them to the laboratory and stored them at 5ºC. Afterwards, we washed the soil to obtain the roots and separated them under the stereoscope in living and dead fractions. We also distinguished between roots from trees and shrubs or herbs, grasses and ferns. We scanned the roots to get data about root morphological traits. Finally, we dried the samples in an oven at 70°C for 48 hours, weighted them and got the fine root biomass and necromass data.

Fig. 3. Ingrowth core study. We marked the places that were resampled to analyze the new root biomass growth with a cylinder plastic tube to be able to take the sample in the same place where we placed the root-free soil. We also protected the place with a plastic mesh to avoid disturbance by animals and with three wooden sticks to make it visible for people, so they would not accidentally destroy it.

Fig. 4. (above, three images). Research assistants who contributed in the field and laboratory work. From left to right: Eriki, Jumanne, Ayubu, Esrom and myself. Upendo and Margreth also did an enormous work in the laboratory contributing to process root samples.

Fig. 5. (below, three images). Minirhizotron study to assess fine root dynamics. From left to right: Minirhizotron installed during two years in a plot in *Podocarpus* forest. Jumanne Mwinyi, research assistant, was responsible for scanning the 60 minirhizotrons distributed along the mountain once per month during two years. Scan image of the roots around a minirhizotron.

To study fine root production we used the ingrowth core approach. This method consisted of sampling soil cores 3.5 cm in diameter down to 40 cm depth, to remove all the visible roots from this soil and refill the same holes with the root-free soil. We marked the places we sampled and waited a couple of months for the roots to grow into the soil. After that time, we resampled the soil and calculated the new root biomass that had been produced. Working with fine roots takes a lot of patience and time in the laboratory. We worked together with four research assistants in Tanzania who supported us in the field work and helped to process more than 1500 soil samples in the laboratory as well as with different research assistants in Germany.

In addition, we conducted a minirhizotron study in 12 natural forest plots along three transects to study fine root production and longevity. A minirhizotron consists of a transparent tube inserted into the soil through which it is possible to see the root around and therefore study their dynamics. In our case, we placed five plexiglass tubes 7 cm in diameter and 45 cm depth in the soil per plot. Every month during a two year period we introduced a scanner (CI-600 Root Growth Monitoring System, Fa. CID, U.S.A.) into the tube to obtain images of the roots. We analyzed these images with the software WinRHIZOTron (Règent, Canada) to study root growth and longevity.

Fine root biomass, necromass and production along the elevational gradient

The higher fine root bio- and necromass values were found in the upper montane forest, known as *Podocarpus* forest (446.86 g•m-2 and 773.25 g•m-2 respectively). The lowest values were found in the savanna for fine root biomass (92.22 g•m-2) and in lower montane forest for necromass (66.57 g•m-2). All these results were in the range of values found in other studies for fine root bio-necromass in tropical forests. Both variables increased with elevation as well as with soil C/N and soil acidity. At the same time, both decreased with mean annual temperature and showed an unimodal pattern in their relation to mean annual precipitation. Our study did not show any influence of the stand structure characteristics on neither of our two variables.

Referring to the fine root production, we found higher values in the upper montane forest (*Podocarpus* forest) (173.14 g•m-2) and the lowest in the subalpine forest (*Erica* forest) (54.9 g•m-2). Fine root production decreased with elevation and increased with mean annual temperature. At low and high mean annual precipitation, fine root production values were low with a maximum at medium mean annual precipitation. There was not a clear pattern that related fine root production with edaphic and stand structure characteristics.

The results of our study showed that at higher elevations, where there is a situation of low temperature, slow decomposition rates and, in summary, difficult conditions for nutrient uptake prevailed, and we found a higher fine root biomass. This strategy can help the plant to cope with these conditions. However, we found a decrease of fine root production with elevation. At lower temperatures, the metabolic activity is lower, and it could be more advantageous for the plants to maintain the structures they already have rather than investing energy and matter in the creation of new ones.

Taking a look into the relation between fine root biomass:aboveground biomass ratio and fine root production:aboveground biomass ratio with elevation, we found that there was a shift of carbon allocation into the fine root system with elevation. This could be explained again by the nutrient limitation at higher elevations and the need of more investment into the fine root system.

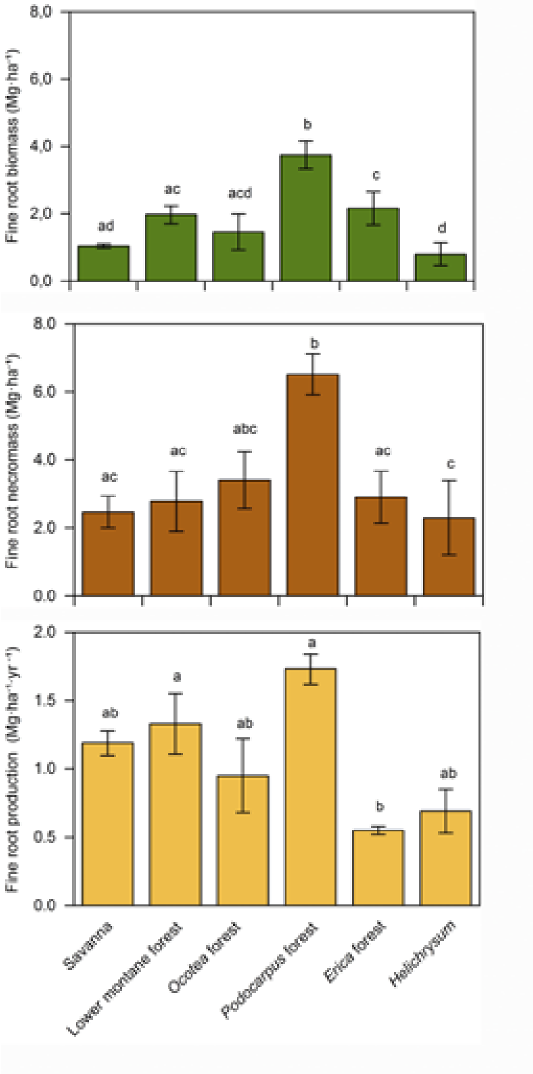


Fig. 6. Fine root biomass (FRB), fine root necromass (FRN) and fine root production (FRP) of six natural habitats along the elevational gradient on Mt Kilimanjaro. Different lowercase letters show significant differences between habitats.

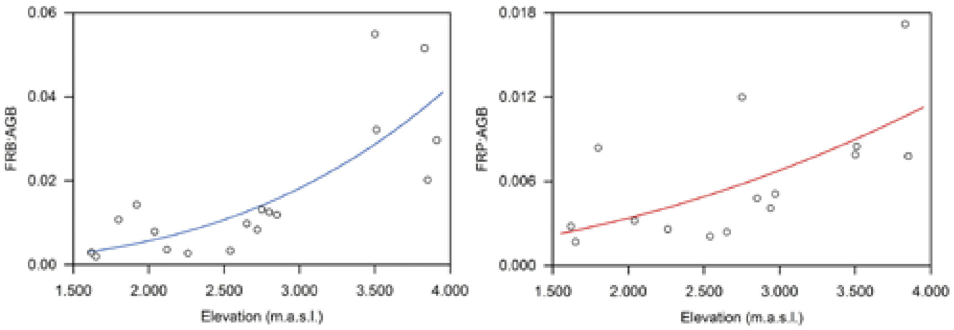


Fig.7. Relation between fine root biomass:aboveground biomass ratio (FRB:AGB) and elevation and between fine root production: aboveground biomass ratio (FRP:AGB) and elevation.

With our results, we confirm the pattern found in other mountains in the neotropics for a paleotropical mountain as Mt Kilimanjaro. We can also use our results to contribute to future studies to understand how carbon and nutrient stocks and fluxes will be affected in the context of climate change.

Fine root biomass and necromass along the land-use gradient

The conversion of savanna woodlands into maize fields resulted in a loss of one third of the fine root biomass. In addition, this biomass was only present during the crop season, which lasted 4–5 months. Focusing on the forest habitats, we found that comparing the fine root biomass of the lower montane forest to the one present in homegardens, coffee plantations and grasslands showed a decrease of a quarter, a third and half of the fine root biomass respectively. Moving up the mountain, the formerly logged *Ocotea* forest presented a threefold higher amount of fine root biomass than the undisturbed *Ocotea* forest. This could be explained by the thick understory layer and the successional stage of this habitat. In the case of the subalpine *Erica* forest, we found a decrease of one quarter compared to *Erica* habitats disturbed by fire.

Our results on fine root necromass showed for almost all habitats the same trend as for fine root biomass, with the exception of *Ocotea* forest, where we found slightly lower values than in the undisturbed forest. In case of disturbed *Erica* forest, we found higher fine root necromass values than in undisturbed habitats.

Land-use change, generally, results in a decrease of fine root bio- and necromass. This fact has consequences for carbon stocks and carbon and nutrient cycles. Management measures like the maintenance of remnants of natural trees in agricultural systems such as coffee plantations and homegardens could help to decrease the impact of land-use change. As there has been an intensification of agricultural land-use at Mt Kilimanjaro over the last 50 years, it is crucial to design, apply and monitor effective, creative and attractive management measures in the management plans for protected areas as well as for the expanding agricultural plantations. The maintenance and building of collaborative projects between agricultural and conservation agencies as well as an easy flux of information between them is crucial for the protection of the rich and diverse landscapes at Mt Kilimanjaro.

Fig. 8. PhD students of SP2, second phase: Natalia Sierra Cornejo (left) and Jerome Kimaro (right).

Distribution and discharge of irrigation canals around Mt Kilimanjaro

by Jerome Kimaro, Valeska Scharsich, Bernd Huwe & Christina Bogner

Background of the study

In many tropical mountainous agro-ecosystems sustainable management of agricultural water is a challenge. It embraces ecological and human aspects and therefore requires a collaboration between scientific disciplines and stakeholders outside science. Indeed, water managers, farmers and hydrologists require a deeper understanding of the actual causes, extent and spatial variability of water-related problems within those agro-ecosystems. Poor water management does not only affect food security and local economies, but could also reduce biodiversity and accelerate the detrimental impacts of climate change.

Topography is known to affect hydrological processes while differences of farming systems can potentially influence variability of crop water demands depending on types of crops grown and agronomic practices. Additionally, the overall management of natural resources by governing institutions has been known to influence the protection of catchment areas and their supplying capacity.

Drawing from empirical insights from a case study around the southern slope of Mt Kilimanjaro, it has been noted that the traditional irrigation canals (Mfongo in Chagga dialect) have been used for decades by Chagga people. Nearly 80% of total mountain discharge is estimated to be consumed by small-scale farmers to sustain several farming systems. Nevertheless, the current discharge of canals around Mt Kilimanjaro is reported to have declined and most of them cannot sustain their discharge throughout the year. The efforts to improve the agricultural water supply failed to succeed so far.

We suppose that hydrological patterns around Mt Kilimanjaro are governed by the complex interaction of several factors operating at variable space and time scales. In this work, we briefly summarize key findings of our study that assessed the major drivers influencing the discharge and the distribution of traditional irrigation canals around the southern slope of Mt Kilimanjaro (Fig. 1). Specifically, we describe the current discharge patterns of irrigation canals along the three main agro-ecological zones, and additionally, we inform about the conveyance and distribution patterns of canals.

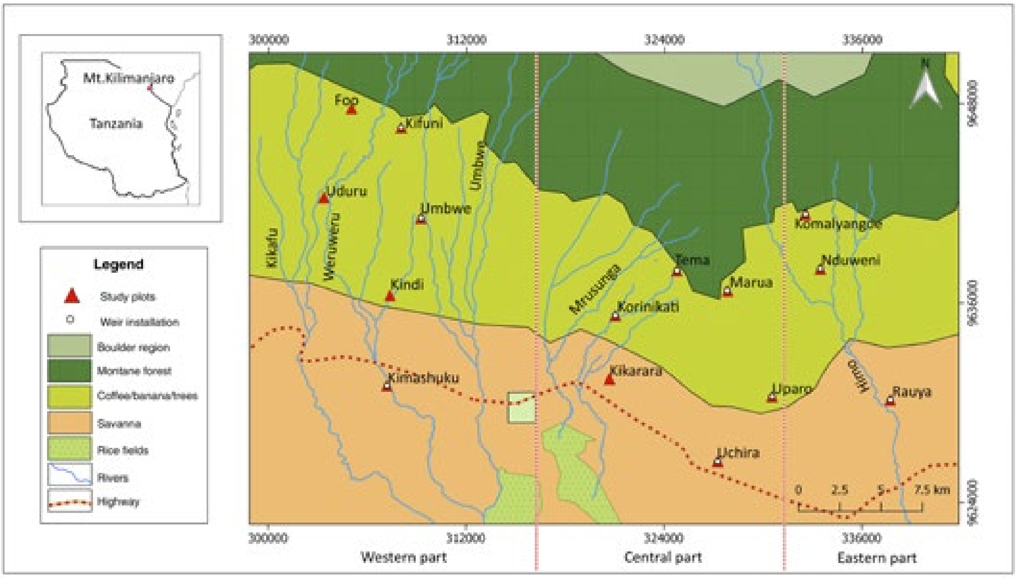


Fig 1. Map of the study area.

Conveyance and distribution of canals around Mt Kilimanjaro

The open earth dug canals are still the major infrastructure for conveying agricultural water through gravity to crop fields around Mt Kilimanjaro. Canals obtain their water both from rivers and springs, most of them confined within the montane forest belt. However, a number of springs are found around the upper cultivated areas. In addition to canals, the Chagga irrigation system is composed of small earth dams, 30–50 m² in size, locally known as Nduwas. Chagga used Nduwas to sustain dry season irrigation or where the sources have a low discharge capacity. Because most Nduwas are situated inside the national park with restricted access, they are difficult to manage.

During field visits, we noted that several farm households had no access to irrigation canals. Canal metrics like length, and geographical orientation and physical locations of their intakes and routes show remarkable differences. Indeed, canals at lower areas were wider (30–45 cm) compared to those in upper areas (15–20 cm).

Canals around the central part were longer compared to those around the eastern part. For example, Machombo and Mzuki canals were more than 7 km long within the cultivation area (Fig. 2B).

However, we could not establish their actual lengths since their sources were located inside the forest (above 2000 m a.s.l). By contrast, canals around the western part were not longer than 1.2 km. However, some canals were combined in order to extend their length. For example, the combination of Mrema canal (1.14 km) and Mwaana canals (1.3 km) around an elevation of 1300 m, could be extended 2.5 km further down-slope, around 1200 m (Fig. 2A).

Furthermore, the overall structure of canal network indicated spatial variability of canal distribution. Although our study lacks quantitative data for computing canal density, like the total lengths of canals and the actual size of irrigation schemes, we suspect that the concentration of canals around upper slopes of the western and eastern parts of the mountain slopes could be relatively higher. Nevertheless, canals around upper areas are less actively utilized for irrigation compared to those located around lower slopes. Based on the local experience of villagers and water experts from the Pangani Water Basin Office (PWBO) and district councils, it was reported that about 1000 to 2000 of primary irrigation canals were estimated to exist around Mt Kilimanjaro. But owing to increased irrigation at lower slopes, there could be a higher proportion of tertiary canals compared to upper slopes. Nearly every farm plot was crossed by a tertiary canal on one side conveying water to the next plot.

We further noted that historical land-use patterns have a direct link to the distribution of canals around Mt Kilimanjaro. Responses during the FGDs indicated that most

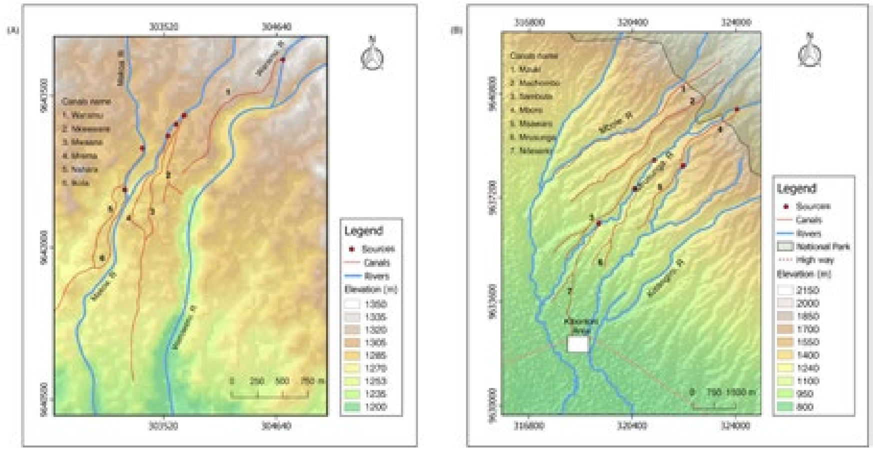


Fig 2. Distribution of canals (left) around Uduru Village, western part of Mt Kilimanjaro and (right) around its central part.

of those canals existing today were built several decades ago by villagers' ancestors and only a few have been added recently. We suppose that the current distribution of Chagga canals still reflects former patterns of land-use, crop types and water demands. Additionally, we suspect that reorganizing the layout of Chagga canals in order to improve water distribution could be difficult. Villagers reported that old canals are an important heritage and hold various cultural values. It was further reported that the lack of readily available labor from the community for canal work is currently a challenge given that establishing canals is laborious and time consuming.

Mountain geomorphology has an influence on routing and orientation of canals. Since Chagga canals are gravity controlled, their flow is highly determined by terrain slope. The findings from analysis of the drainage direction indicated the contrasting orientation of water routes. Most canals around the western and eastern parts were oriented towards south-east direction while those around the central part were towards the west-south direction. Additionally, from topographical analysis we found that the landscape around the central part was rougher due to numerous hills and deep valleys compared to that in the western and eastern parts.

Similarly, most farm plots around the central part were located on steeper slopes (slope > 50%) (Fig. 3) compared to those around western and eastern parts (slope = 15%–30%). Furthermore, we calculated high values of Topographic Wetness Index (TWI>20) around the lower areas indicating that the water would converge towards this zone. This could have some advantages for crop water supply based on the fact that Chagga canals are a gravity type of irrigation.

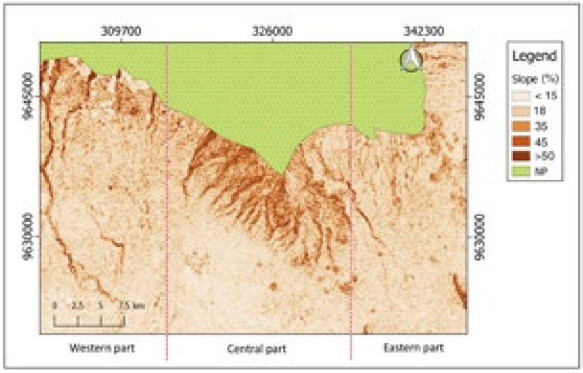


Fig 3. The variation of terrain slope around the southern slopes of Mt Kilimanjaro

Discharge dynamics of canals around Mt Kilimanjaro

Along the three major agro-ecological zones at the southern slopes of Mt Kilimanjaro, the discharge of canals increased with decreasing elevation (Fig. 4). The median daily discharges equalled 7.0, 9.5 and 12.6 l/s in the lower, mid and upper areas, respectively. The discharge also varied across villages in the same elevation zone. For example, among the canals in the lower area, Uchira was dry during the whole observation period, while Kimashuku and Rauya indicated highest values of discharge. Similarly, in the upper area, the value of median discharge in Kifuni was nearly 50% larger than that in Tema.

We attribute this variation to a number of factors, like different demands of irrigation water between upper and lower stream communities. Similarly, failure to repair or clean the canals or over-abstraction could be associated with the low conveyance efficiency. Through Hai and Moshi Rural District Councils, several gravity-free pipelines projects have been established. Given that most of them abstract water from the same intake sources of canals, this could also affect their hydrology. During the FGDs, we were informed by local people that discharge in most canals changed a few years after the installation of the pipelines. Assessments from ten selected villages indicated that 37% of canals could maintain discharge throughout the year, while 41% were seasonal and 22% were already completely dry.

We observed higher discharge during the dry season (July–October) compared to the short rainy seasons (November–January) (Fig. 5). We attribute this to increased irrigation activities during the dry season compared to the wet seasons. Indeed, most canals´ intake are reduced or completely closed during rainy seasons because of decreased irrigation activities. Additionally, closing of canals is used as a strategy of reducing flood risks in villages when rivers overflow.

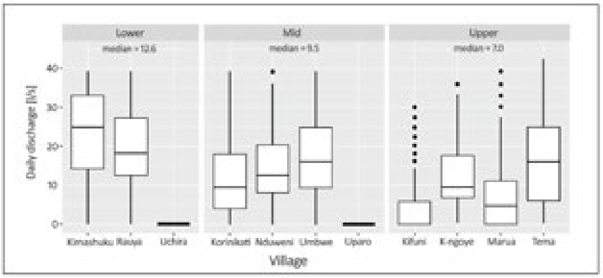


Fig 4. Spatial variation of canal daily discharge around the agricultural area of Mt Kilimanjaro.

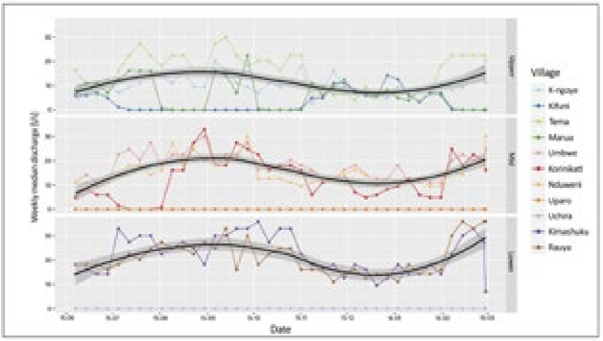


Fig 5. Temporal variation of canal discharge around the agricultural area of Mt Kilimanjaro

Our perspective

Decreasing discharge and drying of canals point at a mismatch between increased water demand and the supplying capacity of the sources. This could lead to food shortage and decreased farm income. Equally important, this problem could increase competition among farmers as well as between the agricultural sector and the natural ecosystem. Our results show that the water resources at Mt Kilimanjaro need to be monitored closely to gain reliable information on discharge variability and a better understanding of its natural and anthropogenic causes.

Fig. 7. Some of the abandoned food crops around Mt Kilimanjaro. From left: Oysternut, air potato, and Wild African yam.

Fig. 6. Measurement of canal flow dynamics by using pressure infrared sensor installed with V-notch 60° weir.

Fig. 8. Irrigating vegetable plots at lower slope areas using traditional irrigation canals.

Subprojects 2 & 3

Soil characteristics at Mt Kilimanjaro

by Joscha Becker, Anna Kühnel, Holger Pabst, James Mnyonga, Emanuel Ndossi, Christina Bogner, Bernd Huwe & Yakov Kuzyakov

Organic matter is an essential component of soils. It provides a carbon and energy source for soil microbes, stabilizes soil particles against erosion and forms a storage for nutrients. Soil organic carbon (SOC) is the major component of organic matter in soils. Thus, its content is a crucial factor for estimating soil fertility and is important in light of climate change. More than 1500 Gt carbon are stored as SOC worldwide. This is about 5 times the amount of C that was emitted by fossil-fuel combustion since 1850. Agricultural management leads to a release from this storage in the form of greenhouse gas carbon dioxide (CO$_2$). When soil organic matter is mineralized this leads to emissions of bound nitrogen in form of another greenhouse gas: nitrous oxide (N$_2$O). The ratio to which organic material is composed of carbon and nitrogen is called the C:N ratio. The soil C:N ratio has a strong effect on the decomposition of organic material, such as plant litter and animal residues. By this, it affects the recycling of nutrients in soil and greenhouse gas emissions from soil. The cation-exchange capacity (CEC) is defined as the ability of a soil to hold cations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), aluminum (Al^{3+}), iron (Fe^{2+}), manganese (Mn^{2+}) and sodium (Na^{+}). These cations are bound to negatively charged clay and organic-matter particles. Once bound, these minerals are not easily lost when the soil is leached by water, and they provide a nutrient reservoir. The bindings are easily exchangeable and the cations may be released into the soil solution. From there they are available to plants and soil organisms. The major cations that are used by plants are calcium, magnesium, and potassium. However, high contents of one nutrient may influence the uptake of other cations. For example, high levels of potassium can limit magnesium uptake by plants even if magnesium levels in the soil are high. In turn, potassium uptake can be reduced by a high calcium content in soils. To identify and evaluate the soil conditions at Mt Kilimanjaro, we used two different soil-sampling approaches: first, we dug a soil profile at each research site to gather information about the depth distribution of soil characteristics and characterize the soil types (Fig. 1 & Fig. 2). Second, we took multiple samples from a fixed depth to cover the variability of each research plot (Table 1). The samples were transferred to our laboratories in Nkweseko (Tanzania), Göttingen (Germany) and Bayreuth (Germany).

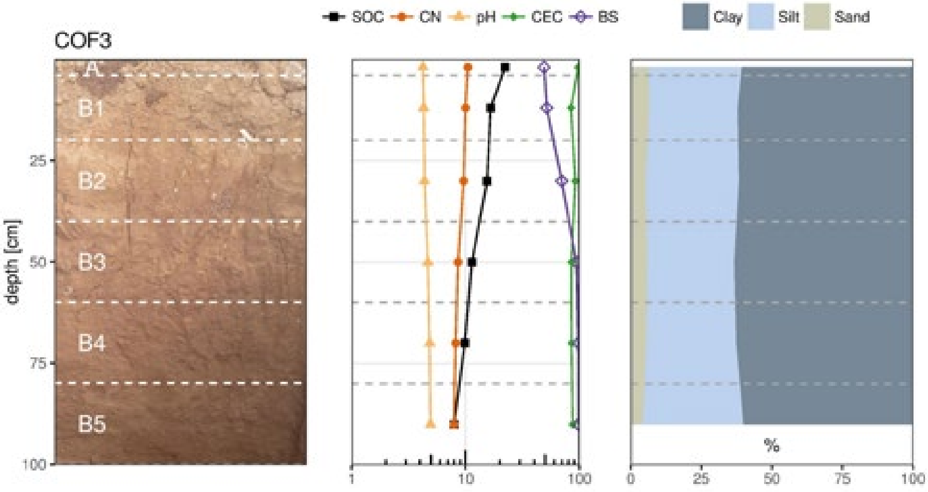


Fig. 1. Soil profile of a Haplic Vertisol at Cof3, basic characteristics: Soil organic carbon (SOC: g kg^{-1}), C:N ratio, pH, cation-exchange capacity (CEC: cmol kg^{-1}) and base saturation (%) and soil texture (clay, silt, sand in %).

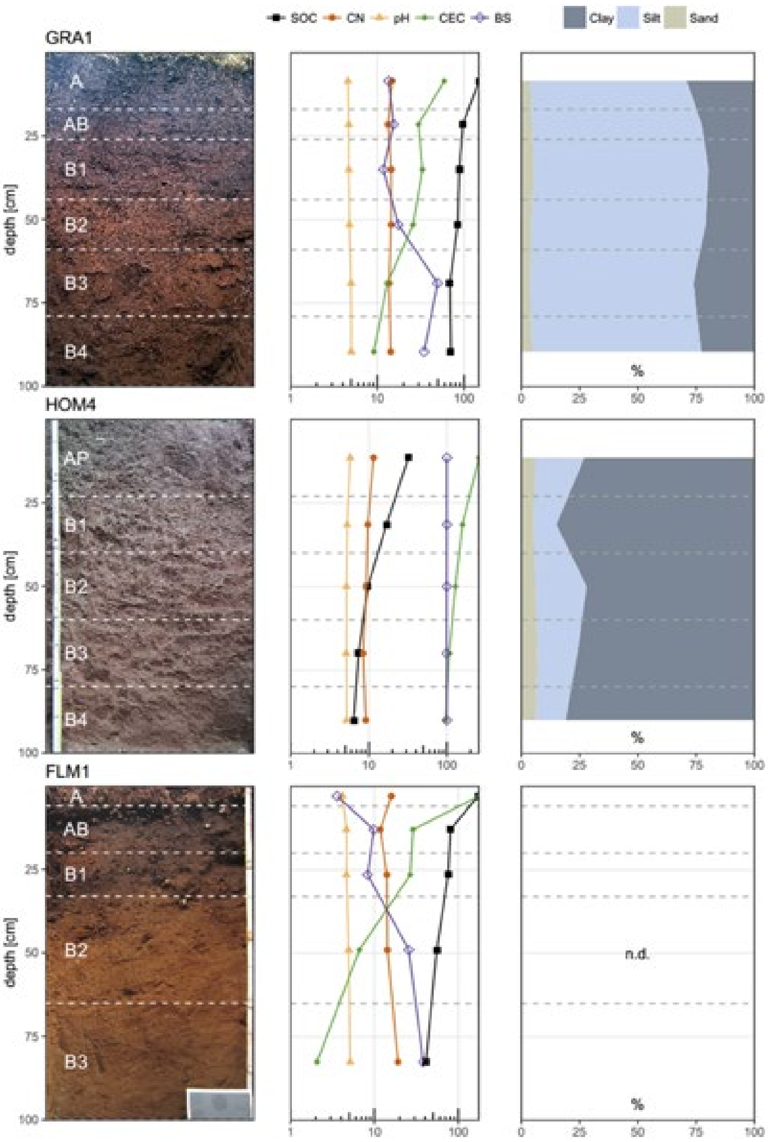


Fig. 2. Soil profiles and soil characteristics under a grassland (Gra1), a homegarden (Hom4) and a lower montane forest (Flm1) at Mt Kilimanjaro.

Carbon and N contents were determined using a dry combustion automated C:N analyzer (Vario EL, Elementar). We considered total C as equal to organic C because the inorganic C content was negligible on our sites. Availability of major nutrient cations (Al^{3+}, Ca^{2+}, Fe^{2+}, H^{+}, K^{+}, Na^{+}, Mg^{2+}, Mn^{2+}) was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) following a preparative extraction in unbuffered salt solution (1 mol/l NH_4Cl). Total cation exchange capacity (CEC) and base saturation were calculated. Soil pH was measured in KCl solution. The sand fraction was determined by wet sieving with Nahexa-meta-phosphate as dispersion agent, after destroying the organic substances. Silt and clay fractions were then measured using a Master Sizer S particle size analyzer (Malvern Instruments). The texture of Mt Kilimanjaro soils is dominated by clay and silt sized particles (Fig. 3). Only soils at *Helichrysum* and in the Savanna zone have a higher share of sand. Soils in the forest zone are very rich in organic matter.

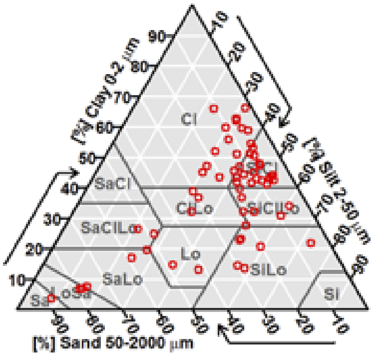


Fig. 3. Soil texture triangle of Mt Kilimanjaro soils. Cl = clay, Sa = sand, Si = silt, Lo = loam.

Major plant nutrients in soil

Nitrogen (N) is an essential element for plant growth. It is found in all plant cells and is part of important molecules, such as proteins, hormones, nucleic acids and chlorophyll. In soil N occurs in organic (humus) or inorganic (ammonium and nitrate) form. Inorganic N is easily available for plants and soil organisms. However, it can also be leached out of soil by heavy rain.

Phosphorus (P) plays a major role in metabolic processes such as photosynthesis (the conversion of the sun's energy to food for the plant) and synthesis and breakdown of carbohydrates. Soil P occurs in both, an organic form and an inorganic form. Its solubility is low and most soil P exists in stable chemical compounds.

Potassium (K) is found within the plant cell solution. It is used for maintaining the turgor pressure of the cell (keeps the plant from wilting) and plays a role in the functioning of stomata and enzymatic processes. Most K in soil (>90%) is part of minerals and is therefore unavailable for plants. When these minerals weather, some K is dissolved in soil water and becomes available. This release of K is mainly depending on climate and mineralogy.

Calcium (Ca) is essential for root growth and health, and the development of leaves. Calcium forms insoluble compounds with other elements in soil (for example P). In this form, Ca is not available to plants. Usually, soils with a higher pH contain more available Ca but high levels of other cations such as Mg, ammonium, iron, aluminum and especially K, will reduce the Ca uptake by plants.

Magnesium (Mg), as a component of chlorophyll, plays an important role in the photosynthesis process. In soil Mg exists as a part of minerals, exchangeably bound to clay and organic matter particles, or available in soil solution. Low pH, low temperatures or dry soil conditions as well as high levels of competing elements K and Ca reduce the availability of magnesium.

Sulfur (S) is a constituent of plant proteins and is involved in plant energy production. Most S in soils is part of organic matter. It is not available to plants in this form but becomes available through mineralization processes. Sulfur deficiencies are more likely in sandy soils with low organic matter.

Most topsoil layers contain more than 10% C (Table 1). Land-use change affects soil properties and fertility. A conversion of natural ecosystems to croplands reduces their productivity, leading to an average decrease in C stocks, with most of the decrease in the highly organic topsoil layers (Fig. 2). This decrease in C contents is accompanied by a release of the greenhouse gas CO_2 from soil that negatively feeds back on the climate system. Lower mountain forests at Kilimanjaro stored up to 10 times more SOC per kg of soil in the upper 20 cm compared to agricultural sites (Table 1). In the savanna zone, SOC content was generally lower than at higher elevations. Here, soils lost about 60% of their SOC when savanna plains were converted into maize fields.

Figs. 4 & 5. PhD students of SP3, Emanuel Ndossi (left) and Joscha Becker (right).

Table 1. Soil carbon and nutrient content in 0–20 cm depth on sites of the savanna and lower montane zone. Nutrient content is divided into plant available (ion) and total (tot) amount.

PlotID	Carbon [g kg^{-1}]	Nitrogen [g kg^{-1}]	P_{tot} [g kg^{-1}]	K^+ [mmol kg^{-1}]	K_{tot} [g kg^{-1}]	Ca^{2+} [mmol kg^{-1}]	Ca_{tot} [g kg^{-1}]	Mg^{2+} [mmol kg^{-1}]	Mg_{tot} [g kg^{-1}]	S_{tot} [g kg^{-1}]
COF1	38.6	3.2	2.2	6.6	2.3	23.0	1.0	5.2	2.0	0.7
COF2	53.4	4.4	3.4	9.1	3.0	91.9	3.0	11.5	3.8	0.8
COF3	17.8	1.8	1.9	5.0	2.7	32.5	1.4	6.3	3.2	0.6
COF4	30.3	2.4	2.0	22.6	3.5	161.4	4.3	29.9	3.3	0.5
COF5	65.5	4.6	2.6	7.4	1.1	67.9	2.2	15.1	3.4	0.6
FLM1	107.7	8.0	1.5	1.8	1.4	0.8	2.1	0.9	1.9	1.2
FLM2	201.7	12.5	1.7	4.3	1.1	12.5	1.1	5.1	2.0	1.3
FLM3	62.3	5.0	1.6	4.6	1.0	232.0	13.3	93.2	20.8	0.5
FLM4	72.2	5.8	1.7	4.7	1.1	290.7	7.6	87.0	9.6	0.6
FLM6	172.2	10.4	1.8	2.7	1.0	16.8	5.1	7.0	5.5	1.0
GRA1	140.8	9.6	2.6	1.7	1.9	2.4	1.6	1.3	2.5	0.9
GRA2	34.1	2.4	1.8	0.8	0.4	6.3	0.3	1.4	4.1	0.4
GRA4	16.7	1.3	0.8	3.6	1.2	128.3	12.7	51.9	13.7	0.3
GRA5	21.9	1.4	1.6	1.6	1.7	114.6	32.8	61.5	38.4	0.6
HOM1	80.8	6.4	3.4	2.8	2.1	4.5	2.0	0.5	2.8	1.0
HOM2	26.1	2.3	1.9	16.1	2.9	123.3	3.0	33.0	2.3	0.4
HOM3	71.9	5.2	1.7	1.3	0.7	9.7	0.5	6.1	5.7	0.5
HOM4	37.4	3.4	1.4	3.6	0.8	150.8	3.6	81.9	3.3	0.5
HOM5	43.1	3.7	2.0	15.0	1.7	162.6	3.6	64.2	5.2	0.5
MAI1	13.6	1.2	1.1	6.9	2.4	35.4	1.1	13.8	1.6	0.2
MAI2	18.9	1.5	2.4	19.9	3.1	143.7	3.0	71.8	4.6	0.2
MAI3	21.6	1.7	2.6	25.1	5.0	245.7	16.0	82.2	14.3	0.5
MAI4	10.1	0.9	2.6	22.0	2.9	85.2	3.0	73.5	6.0	0.2
MAI5	10.1	1.0	3.2	11.6	2.8	88.2	2.4	59.4	4.8	0.2
SAV1	20.2	1.6	2.0	3.7	3.7	197.4	24.5	61.6	17.5	0.5
SAV2	17.1	1.4	1.3	11.5	1.8	632.0	32.2	86.3	59.4	0.5
SAV3	36.4	2.3	0.9	5.2	2.3	232.9	22.0	79.8	15.9	0.5
SAV4	29.9	1.7	0.6	10.5	0.7	636.6	88.6	124.6	42.3	0.9
SAV5	22.3	1.7	3.9	22.0	5.4	137.9	4.3	86.5	5.9	0.3

Subprojects 2 & 4

Variability of soil physical parameters, soil moisture and soil erodibility in the coffee and homegarden ecosystems

Coffee yields were once the most important cash crop in the Kilimanjaro area. The Kilimanjaro Native Co-Operative Union (KNCU) is Africa's oldest cooperative and coffee is their most important cash crop. They farm the volcanic soils of the massive Mt Kilimanjaro to produce wet processed (washed) Arabica coffee. The coffee trees are often inter-cropped with bananas in the Chagga homegardens. More than 150,000 small-scale farmers from nearly 100 village societies provide about 5,300 tons of Arabica coffee to the KNCU. This coffee comprises about 60% of the region's coffee, although this varies with the market and private trading agreements that provide competition. Kilimanjaro coffee exhibits distinct origin tasting flavours along with a lovely body and shining acidity that have given it a reputation as one of Africa's best coffees. At independence most large scale coffee farms and other commercial plantations owned by non-Tanzanians were expropriated leading in almost all cases to an economic break-down. In the past 20 years however, commercial coffee plantations were increasingly re-established, sometimes even by their former owners now leasing the land. In contrast to local small-scale coffee farmers commercial coffee plantations are mostly monocultures of just coffee trees with a high demand of water and the intensive use of pesti- and herbicides. Organic grown coffee is very rare world-wide especially since coffee has multiple pests attacking all parts of the plant, especially when grown in monocultures. However, the region's organic premium farmers help to protect the fertility of the volcanic soils and also maintain shade trees. The coffee farmers are rewarded with higher profits as well as decreased health risks due to the elimination of intensive chemical farming.

The aim of our project was to compare coffee yields of an organic managed plantation in the Uru region situated between 1400 and 1600 m a.s.l. (MACHARE ESTATE) to conventional coffee plantations with regular chemical treatments.

We were studying the following treatments:

1. no removal or mowing of weeds
2. mowing of weeds without removal
3. mowing and removal of weeds
4. the same treatments but only on the rows between the coffee trees
5. pesticide spraying.

The experiment is still ongoing.

Preliminary results

Investigation of the root system of coffee fields treated with herbicides showed that the root system of the coffee trees was very much reduced. Living roots were only seen in the immediate vicinity of manure (synthetic fertilizer). The root system of coffee trees not treated with herbicides on the other side had a wide-spread strong root system. Coffee trees with a reduced root system are more susceptible to drought as experienced 2016/2017 where the yields of coffee dropped considerably by 40% even if irrigated. Organic grown coffee on the Machare Farm on the other hand had 20% more yield in the same year obviously because the root system stabilized the plants, despite the fact that these coffee trees were not irrigated. Also the quality of the beans (bigger size) was better compared to the harvests of chemically treated coffee in the same year (data: B. Luther-Medoch).

Coffee yields in plowed fields on the organic farm and those where weeds were just short-cut or removed showed no differences.

Organic managed coffee is more resilient to extreme climatic conditions

These first results of our study on an organically managed compared to conventionally managed coffee plantations showed that coffee trees on the organic plantation had a stable and dense root system and produced a better coffee yield even during climatic unfavourable conditions. Conventional coffee farmers with a high usage of herbi- and pesticides had to irrigate their coffee fields to avoid that large areas were dying off and suffered from a considerable drop in coffee yields.

Organic managed farms protect biodiversity

Comparing the biodiversity of Orthoptera showed that on heavily treated coffee plantations sometimes only three species could be found while in the Chagga homegardens and especially on the organically managed farm much more species were counted (Table 1).

Chemical treatment is expensive and harmful to human health

Of course the facts that herbi- and pesticides are expensive and harmful especially to those farmers applying the chemicals manually must be considered. Questionnaires showed that many farmers believe that having this "medicine" (herbi- and pesticides) at home and being exposed to it while applying it is responsible for cancer and other severe diseases.

Summary

Organically managed coffee farms help to retain a high biodiversity, harbour many indigenous shade trees and are less water demanding than conventional coffee plantations with high water demands, a low biodiversity and a reduced tree cover often consisting of introduced tree species.

Fig. 1. Organically managed plantation (Bente Luther-Medoch) with plenty of mostly indigenous shading trees and an intact herb layer.

Table 1. Orthoptera species in coffee plantations and Chagga homegardens.

Plot	management	species no	elev.
Cof 6	(organic)	25	1500 m
Cof 5	(conventional)	9	1660 m
Cof 4	(conventional)	6	1120 m
Cof 3	(conventional)	3	1300 m
Cof 2	(conventional)	9	1360 m
Cof 1	(conventional)	14	1300 m
Hom 5	Chagga homegarden	21	1560 m
Hom 4	Chagga homegarden	29	1260 m
Hom 3	Chagga homegarden	20	1840 m
Hom 2	Chagga homegarden	25	1150 m
Hom 1	Chagga homegarden	20	1640 m

Fig. 2. Differently managed organic plantation where the weeds are removed about 1–1.5 m along the coffee tree rows.

Fig. 3. Conventional managed coffee plantation in the same area with very few and mostly introduced (*Grevillea*) shade trees and an irrigation pipe system. Such a field is treated several times per season with herbi- and pesticides.

Please visit: www.macharecoffee.de

Additional source: https://espressocoffeeguide.com/gourmet-coffee/arabian-and-african-coffees/tanzania-coffee/tanzania-kilimanjaro-coffee/

Subproject 3

Linking nutrient cycles, land-use and biodiversity along an altitudinalgradient at Mt Kilimanjaro

Impacts of climate and land-use on N_2O and CH_4 fluxes from tropical ecosystems in the Mt Kilimanjaro region, Tanzania

by Ralf Kiese, Imani Kikoti, Adrian Gütlein & Friederike Gerschlauer

Fig. 1. Top: Manual chamber sampling of soil N_2O and CH_4 fluxes. Left: Soil core sampling at *Helichrysum* (4000 m. a.s.l). Right: Laboratory soil core N_2O and CH_4 fluxes.

Tropical ecosystems are important for global climate and biogeochemical cycles, due to their enormous exchange of energy, water, carbon, and nutrients with the global atmosphere. Tropical forests contain ~25% of the terrestrial biospheres carbon, account for ~33% of the terrestrial net primary production, and play an important role in buffering the atmosphere against increasing carbon dioxide (CO_2). Despite the overall importance of this biome to biogeochemistry and biological diversity, essential uncertainties remain in our understanding of nutrient cycles. Especially in Africa our ability to predict ecosystem functions is behind many other tropical ecosystems. This deficit is especially pronounced for soil nitrous oxide (N_2O) and methane (CH_4) emissions, besides CO_2 two other important greenhouse gases. The soil-atmosphere exchange of N_2O and CH_4 result from soil microbial processes depending largely on soil environmental conditions such as temperature and moisture. Consequently, climate and land-use change are expected to influence soil microbial processes and thus soil greenhouse gas exchange.

From 2011 until 2015 we quantified soil N_2O and CH_4 fluxes from tropical forest, agroforest, arable and savanna ecosystems in the Kilimanjaro region, Tanzania, combining in situ chamber and laboratory soil-core incubation techniques (Fig. 1). Although there were distinct differences from ecosystem to ecosystem, soils generally functioned as net sources for N_2O and net sink for CH_4. Due to moderate soil moisture contents N_2O emissions of tropical montane forests were generally low. For the same reason forest soils were a significant sink of atmospheric CH_4, regardless of low mean annual temperatures at higher elevation e.g. at *Erica* forests and *Helichrysum*. Mainly due to soil compaction and use of nitrogen fertilizer, land-use intensification increased soil N_2O emissions and decreased soil CH_4 uptake. Compared to land-use change induced decreases in vegetation and soil carbon stocks, alteration of soil N_2O and CH_4 emissions following conversion of forests into coffee or homegardens were of lower importance in the overall ecosystem greenhouse gas balance.

However, due to much lower ecosystem carbon stocks in soils and vegetation, this was different when converting savanna into agriculturally used systems such as maize.

Overall the protection and sustainable management of vegetation and soil carbon stocks is most crucial for mitigating greenhouse gas emissions from land-use change of tropical systems in Africa and world-wide.

Carbon and nutrient input by litter fall and litter decomposition

by Joscha Becker, Holger Pabst, James Mnyonga & Yakov Kuzyakov

Fig. 1. Litter trap at *Erica* forest (A) and microcosms for leaf litter decomposition at lower montane forest (B).

Carbon and nutrient cycling are fundamental ecosystem functions that control C storage and pools, provide plant nutrients and regulate microbial and faunal activity. Soils, as the linkage between abiotic and biotic components of an ecosystem, are strongly affected by changes in these cycles. To understand the impacts of climate and land-use changes on biodiversity and associated ecosystem services and stability on Mt Kilimanjaro, detailed understanding and description of the current biotic and abiotic controls on ecosystem soil C and nutrient fluxes are needed. Therefore, this research described and quantified cycles of C and major nutrients (N, P, K, Ca, Mg, Mn, Na, S and Si) along a 3400 m elevational gradient and across three stages of land-use intensity. The objective was to assess the effects of land-use change and climatic variation along the elevational gradient, on litter fall, litter quality, litter decomposition, and C stabilization in soil. Litterfall was measured every two weeks over one year and inputs of C and nutrients were calculated (Fig. 1A). Decomposition rates of native (Fig. 1B) and standardized litter were quantified and TBI indices for decomposition and C stabilization were used to assess seasonal variabilities. Annual patterns of litterfall and decomposition were closely related to rainfall seasonality and temperature. Leaf litterfall contributed 60–75% to total litterfall and decreased from 1900 to 2900 m a.s.l. Within the same elevation range, annual litter decomposition decreased by about 25%. Further decrease of decomposition rates in (sub-) alpine ecosystems indicated a strong decline of productivity and turnover at 2900 m and above. Maxima of decomposition rates occurred between 1900 and 2500 m and were linked to the seasonal homogeneity of temperature and moisture availability (Fig. 2).

At this elevation, litterfall, decomposition rates and C stabilization showed the least seasonal variation. Ecosystems below 1900 m were subjected to pronounced seasonal moisture limitation. Particularly C stabilization in savanna (950 m) was up to 23 times higher during the rainy season compared to the dry season. Above 2900 m, seasonality increased again with lower annual precipitation and greater temperature limitation during cold seasons. Land-use change from natural forests to agroforestry systems increased litter macronutrient content and deposition (N, P, K), thus enhancing biogeochemical cycles. Carbon stabilization in these ecosystems and in the colline zone was reduced by about 30% by land-use intensification. Soil microbes in these ecosystems were less efficient in soil organic matter (SOM) decomposition but at the same time more demanding for new C sources.

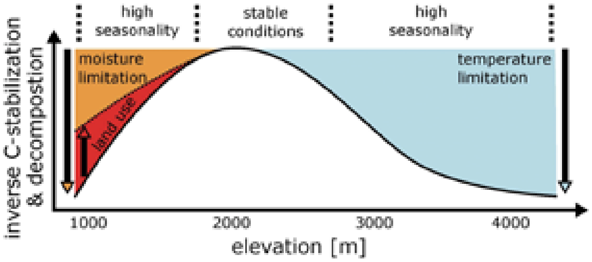


Fig. 2. Climate and land-use effects on standardized litter decomposition at Mt Kilimanjaro.

Effects of elevation on soil microbial communities and organic matter composition

by Joscha Becker, Anna Gunina, Michaela Dippold, Andreas Hemp & Yakov Kuzyakov

Tropical mountain ecosystems cover a broad variety of climatic and vegetation zones and are a global hotspot of biodiversity. The structure of microbial communities governs the allocation of C in soil and affects ecosystem C cycles and soil organic matter composition (SOM). The elevational gradient of a mountain provides an ideal situation to investigate the response of soil microbial communities to climatic variability. Composition and quality of SOM are strongly related to the input, the stability and the turnover of C in soil. While a lot is known about quantitative effects on soil C, the variation of SOM chemistry across ecosystem scales and its relation to climate, vegetation and abiotic factors remains poorly understood. Topsoil samples (0–10 cm) were analyzed for C and N content, pH, microbial biomarkers and soil organic matter chemical composition (py-GC/MS – Fig. 1). Changes in the composition of microbial communities along the slopes of Mt Kilimanjaro are a result of this climatic optimum and the consequent niche differentiation of certain groups. With increasing elevation and the harsh environmental conditions in the alpine zone above 4000 m (low temperature, low soil C and N contents), gram-positive bacteria were replaced by fungi. These variations were indirectly dependent on climatic factors, and mainly explained by changes in vegetation composition and soil parameters.

Ecosystems at mid elevation (~2000 m) represented the interception zone of optimal moisture and temperature conditions throughout the year. High litter inputs and fast turnover controlled the C sequestration in these ecosystems, while climatic restraints on decomposition limited the C turnover in soils at lower (drought) and higher elevation (low temperatures). Soil organic matter chemistry in Mt Kilimanjaro forests was strongly dependent on a precipitation and temperature equilibrium. High ecosystem productivity at mid-elevations led to increased amounts of volatile compounds but at the same time increased stable carbon pools.

Fig. 1. Pyrolysis GC/MS at the University of Göttingen.

Subproject 4

Plant diversity and performance in relation to climate and land-use on Mt Kilimanjaro: communities, species, populations, ecological genetics

Tree growth and water use dynamics at Mt Kilimanjaro, Tanzania

by Andreas Hemp, Reiner Zimmermann & Sabine Remmele

Natural tree species distribution at Mt Kilimanjaro is driven by climatic and edaphic factors. In our studies we aimed to answer the following questions: Which growth dynamics do have the forests of Mt Kilimanjaro today? Is tree growth continuous, seasonal, or episodic? Are there relationships between past and recent climate, tree growth, temporal water stress and water use? For the first time at Mt Kilimanjaro, we combined systematic eco-physiological observations of intra-annual tree growth and water use with the response to site climate and linked it to tropical wood anatomy and a retrospective dendro-climatological analysis.

Tree stem growth was monitored for several years at seven sites and on more than one hundred tree individuals with high resolution dendrometers along an elevational gradient from savanna forests through all montane forests up to the afro-alpine tree line. Here, we present two results as examples of our studies: First, tree growth at the Mrusunga lower montane valley forest with *Entandrophragma excelsum* – the tallest tree species of Africa – and second, tree growth and water use of *Erica trimera*, the tree species forming the afro-alpine tree line.

The tree species *Entandrophragma excelsum* was found in the rare "*Newtonia* ravine forest type" around 1625 m a.s.l. at the south-east slopes of Mt Kilimanjaro. This unique, very tall relict forest was recently found by us to harbour Africa's tallest trees, reaching up to 81.5 m in height. Four years of continuous high resolution dendrometry showed that radial stem growth of *E. excelsum* occurs almost exclusively during the main rainy season. All other months were a phase of slow growth or complete cambial dormancy. The onset of tree growth is triggered by the onset of the main rainy season. Duration of growth is not correlated among trees. The completion of seasonal growth varies sometimes by more than 50 days. The onset, growth duration and closure of annual growth varied significantly by year and trees. This indicated that other triggers besides the precipitation influence the cambial activity. Tree core samples of *E. excelsum* at Mt Kilimanjaro did not show any distinct tree ring boundaries which could be assigned to annual growth. Thus dendrochronology methods could not be applied. The annual maximum radial growth recorded with dendrometers was 2.1 mm. Given the observed stem diameters over 200 cm at Mrusunga, the tree age estimate is more than 850 years for the largest tree.

In contrast, the stout trees of *Erica trimera* at the upper treeline at 3950 m a.s.l. reached more than 10 m height and up to 63 cm in stem diameter. They showed an almost continuous radial stem growth independent of seasonal climatic variations and day length. Large individuals were sampled for tree ring analysis. Visible radial ring growth varied from 0.2 to 1.5 mm per year. Assuming average growth rates, the estimated age of the larger individuals is over 800 years. Tree growth appeared to be limited by low temperatures, frost and wind. Sap flow of *Erica trimera* was measured for more than one year. Tree transpiration was directly related to the vapour pressure deficit of the air thus determined by air moisture content and the irradiation-driven air temperature.

Fig. 1. Sabine Remmele reading out dendrometrical data.

Fig. 1. Mrusunga Valley tree coring on *Entandrophragma excelsum* 2015 (Photo: Sabine Remmele).

Africa's highest mountain harbours Africa's tallest trees

by Andreas Hemp, Reiner Zimmermann, Sabine Remmele, Ulf Pommer, Bernd Berauer, Claudia Hemp & Markus Fischer

While world records of tree heights were set by American, Australian and Asian tree species, Africa seemed to play no role here. In our study we show that *Entandrophragma excelsum* (Meliaceae) found in a remote valley at Kilimanjaro had to be included in the list of the world's superlative trees. A unique combination of anatomical peculiarities and favorable site conditions might explain their enormous size. The late date of this discovery of Africa's tallest trees may be due to the comparably low study efforts at Kilimanjaro compared with other biodiversity hotspots. Since only a few square kilometers of this habitat of *Entandrophragma* are left, Kilimanjaro (and Africa) is about to lose not only a unique biogeographical archive with highly diverse vegetation, but also its tallest trees. The inclusion of these valleys into the immediately neighbouring Kilimanjaro National Park would be an excellent and urgent possibility of protection.

The giant *Entandrophragma excelsum*, a species that is typically found in moist evergreen forests of Uganda, Togo and Tanzania, might be over 850 years old as latest investigations suggest. Researchers first noted the mammoth size of some of the valley's trees during an expedition 20 years ago, but the location's remoteness kept the true height of its vegetation a secret until researchers had better gadgets to measure the trees growing on one of the research plots established by the KiLi Project.

The massive trees play an important role in the mountain´s ecosystem, harbouring ferns and multiple other plants that grow on them for physical support. They are like a city in the forest. But the green giants face the threat of illegal logging, which plagues their precious habitat. Only few patches of this submontane forest remain on Kilimanjaro.

Fig. 2. *Erica trimera* site – sap flow and dendrometry at 3950 m a.s.l. 2015 (Photo: Reiner Zimmermann).

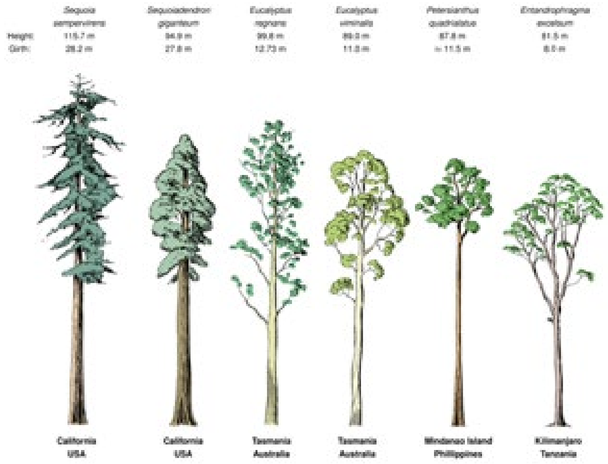


Fig. 1. The height, girth, and locations of some of the world's tallest tree species.

Fig. 2. The tallest trees got quite some attention. Dr. F. Shoo, the Bishop of Tanzania and part of his team were the first officials in March 2016 taking the strenuous walk to see the giants.

Fig. 3. Profile (45 x 5 m) of a submontane forest at 1620 m a.s.l. on the southern slope of Kilimanjaro (Flm4). **Aa:** *Aningeria adolfi-friederici* (dead) **Cb:** *Casearia battiscombei*, **Cp:** *Chassalia parvifolia* **Ee:** *Entandrophragma excelsum* **Ga:** *Garcinia tanzaniensis* **Hd:** *Heinsenia diervilleoides* **Lb:** *Landolphia buchananii* **Lu:** *Leptonychia usambarensis* **Sg:** *Syzygium guineense* **Ss:** *Strombosia scheffleri* **Uh:** *Urera hypselodendron*. Mean canopy height of 40 m with some emergent trees (*Entandrophragma excelsum*) reaching heights of over 60 m and densely covered by epiphytes (*Drynaria volkensii*). In the upper part of the profile lianas and shrubs form dense thickets under a gap in the tree canopy.

Fig. 4. *Entandophragma excelsum*, Mkukusu in Swahili and Ipong´u in Kichagga is the tallest tree species in Africa.

Fig. 5. In February 2017 the Regional Commissioner of Kilimanjaro, Said Meck Sadiki, the District Commissioner of Moshi, Kippi Warioba, and Mrs Betrita Loibooki, KINAPA Chief Park Warden, visited the trees in the remote Mrusunga Valley (background).

Generation of a high-quality physiographic map as a base for ecotourism, nature conservation and land planning

by Andreas Hemp, Ethan Oleson & Manfred Buchroithner

The KiLi Project was based on the data set compiled mainly on vegetation data of previous DFG funded projects from 1996 onwards. Over 1600 vegetation plots were used with intensive land surveys to prepare a first detailed vegetation map of Mt Kilimanjaro. This map was taken to develop a high-quality physiographic map as a base for ecotourism, nature conservation and land planning (**Fig. 1**) at a scale 1:100,000 for the entire Kilimanjaro massif. Ethan Oleson did the cartographic work for his Master thesis in the frame of the KiLi Project.

Besides a highly accurate relief representation (with elevation contours, spot-heights, hill-shading and rock-drawing) the map shows the complete infrastructure of the national park (incl. climbing routes, drink-water holes, camp-sites) as well as the current vegetation distribution and land-use. With this the map represents an important tool for land and nature management and planning, e.g. for the national park authorities, the rural land planning division and environmental NGOs as well as an important scientific and logistic base for researchers. Tourists and tourist guides will find it useful to get information of the environment along the climbing routes and will get attracted to other destinations outside the national park thus enhancing touristic activities beside the normal climbing tourism. This might help to increase eco- and cultural tourism inside the villages.

The map is in English and German. The quality of the map product can well compare with other high-quality maps published in Germany, like the map series of the Consortium for Comparative High-Mountain Research (Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung, ARGE), which is the distributer of this new Kilimanjaro map.

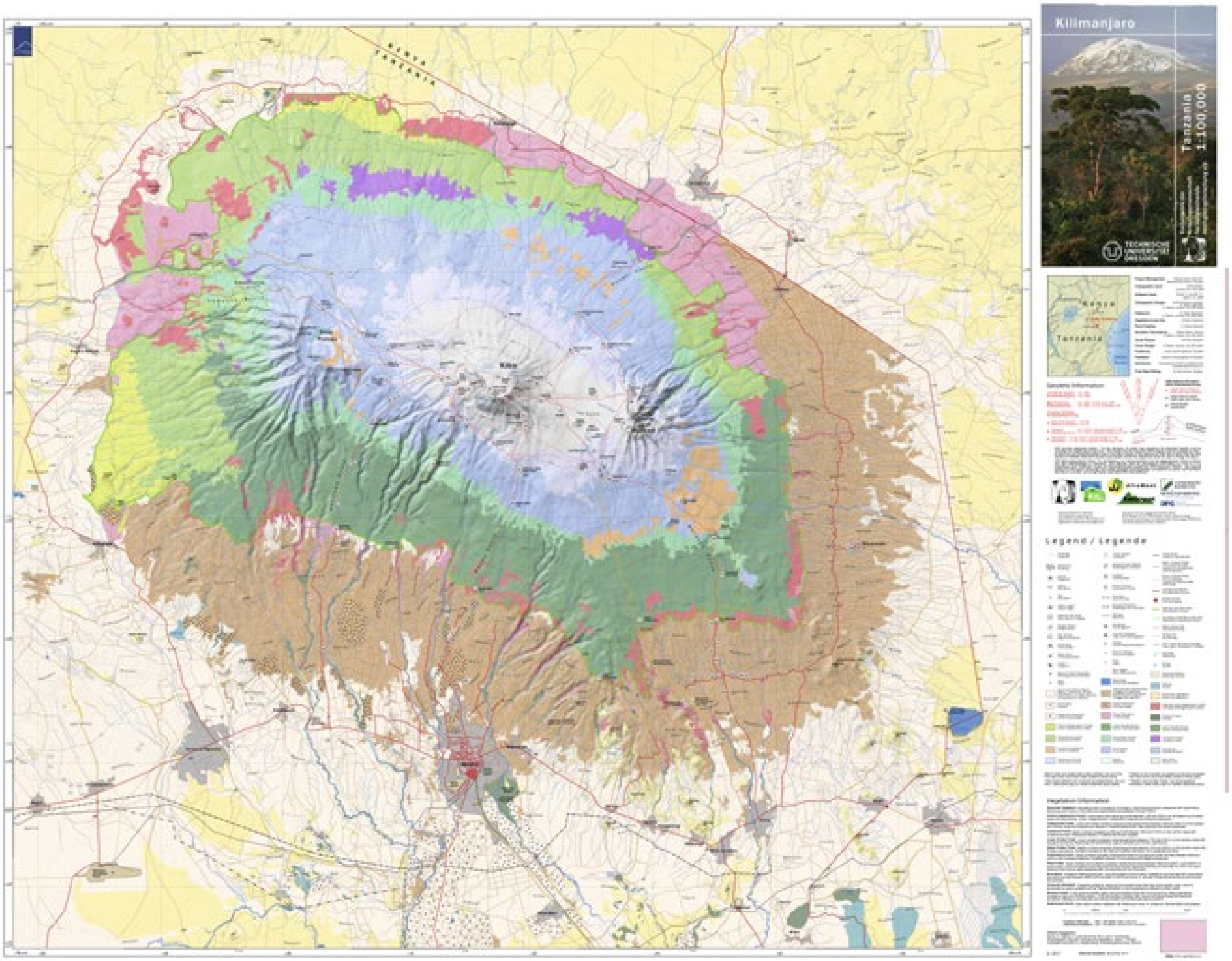
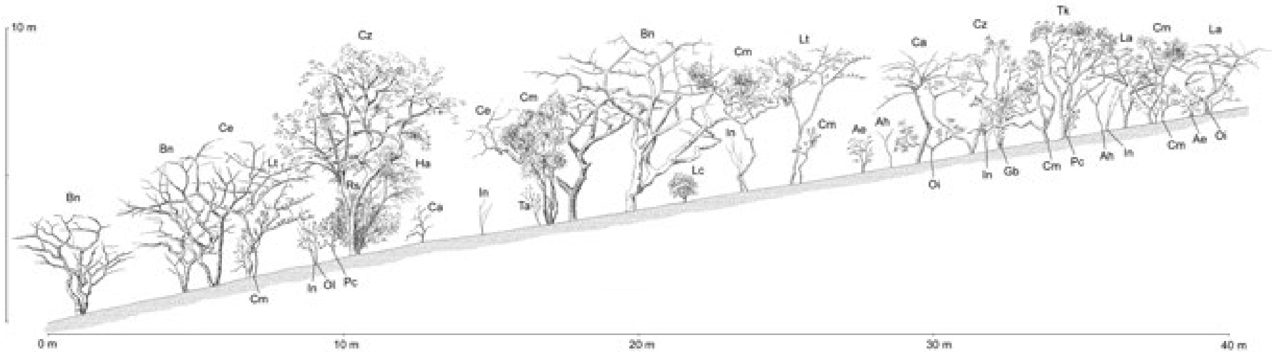


Fig. 1. Physiographic map of Mt Kilimanjaro.

Citation: Hemp, A., Oleson, E. & Buchroithner, M.F. (2017): Kilimanjaro. Physiographic map with land-use and vegetation, scale 1:100,000. Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung, Munich.



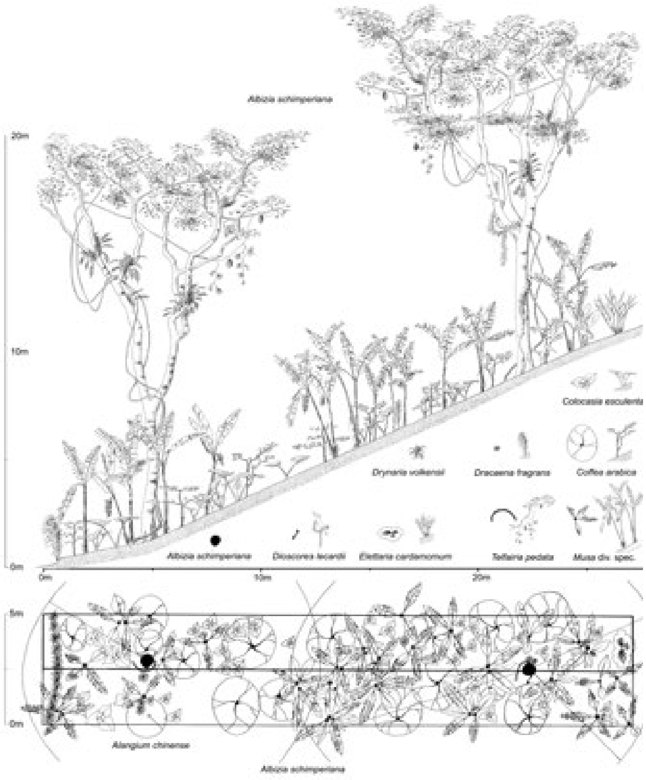


Fig. 1 (above). Vegetation profile of savanna research plot Sav4, eastern slopes of Kilimanjaro, Chala area.

Fig. 2 (left below). Profile of a "Chagga homegarden", research plot "Hom4", eastern slopes of Kilimanjaro.

Tree inventory of Mt Kilimanjaro

by Andreas Hemp, Gemma Rutten, Andreas Ensslin & Ulf Pommer

An inventory of the trees of all major habitat types for providing basic data for all other subprojects was conducted for all plots. Every tree with more than 10 cm diameter was measured (diameter and height) and its exact position located on the plots. Furthermore, all trees were labelled and identified to species level. Exemplary for the different habitat types profiles are shown here (prepared by A. Hemp), giving accurately the growth shape, size and location of the trees within the research plots as seen along a lateral transect and from above.

Obtaining all these data of a research plot for example in the montane forest sometimes took more than a week of continuous work.

This data set is useful to determine the biomass of a certain forest, delivers information on the structure of the different forest types and its regeneration potential and about the carbon storage capacity. Ulf Pommer, a highly skilled forester, worked as a technician for the KiLi Project in order to obtain reliable data. A second inventory, already started in 2017, will deliver insight of the rate of biomass growth for the different forest types from the savanna to the afro-alpine zone and thus detailed data on the productivity of Kilimanjaro´s forests.

Fig. 3. Research plot in the middle montane zone, *Ocotea* forest (Foc1).

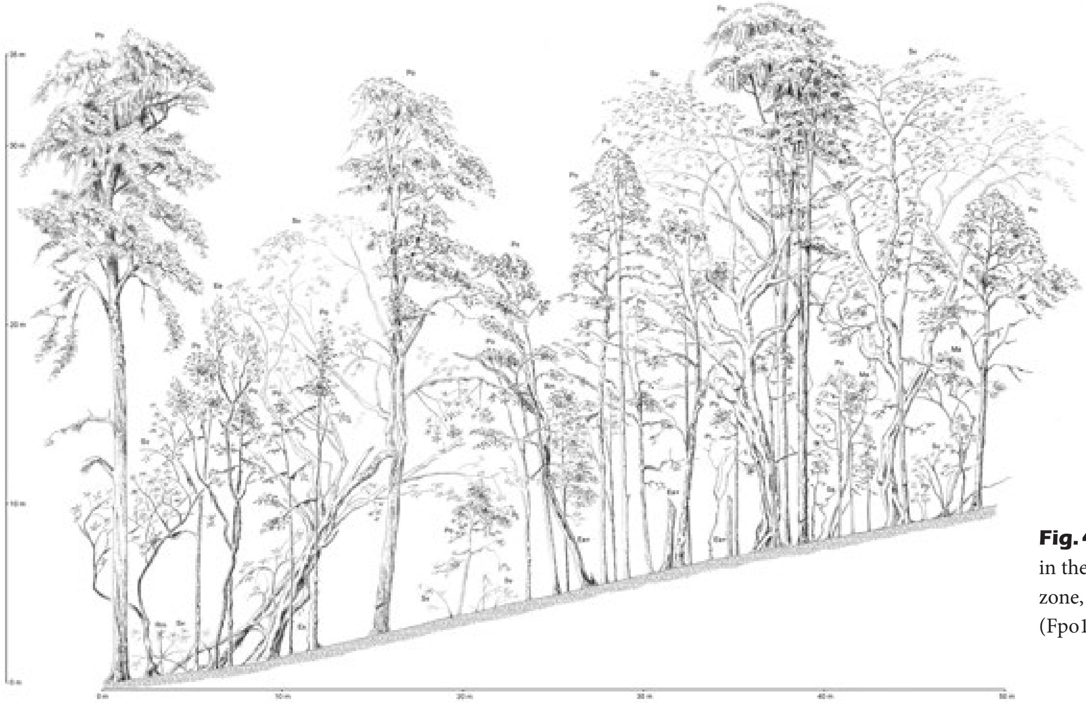
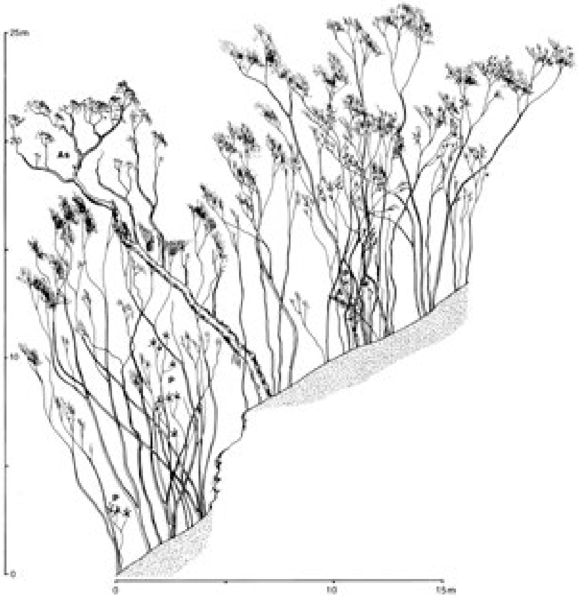


Fig. 4. Research plot in the upper montane zone, *Podocarpus* forest (Fpo1).

Fig. 5. Ulf Pommer measuring the heights of all trees growing on research plot FPo4, a *Podocarpus* forest at 2720 m along the Maua Rescue Route. The red arrows point at the metal labels. Each tree on each KiLi research plot was marked with such labels and identified to species level.

The profile of a similar forest is shown in Fig. 4. To obtain such a drawing required about one week of field work and one week drawing the profile.



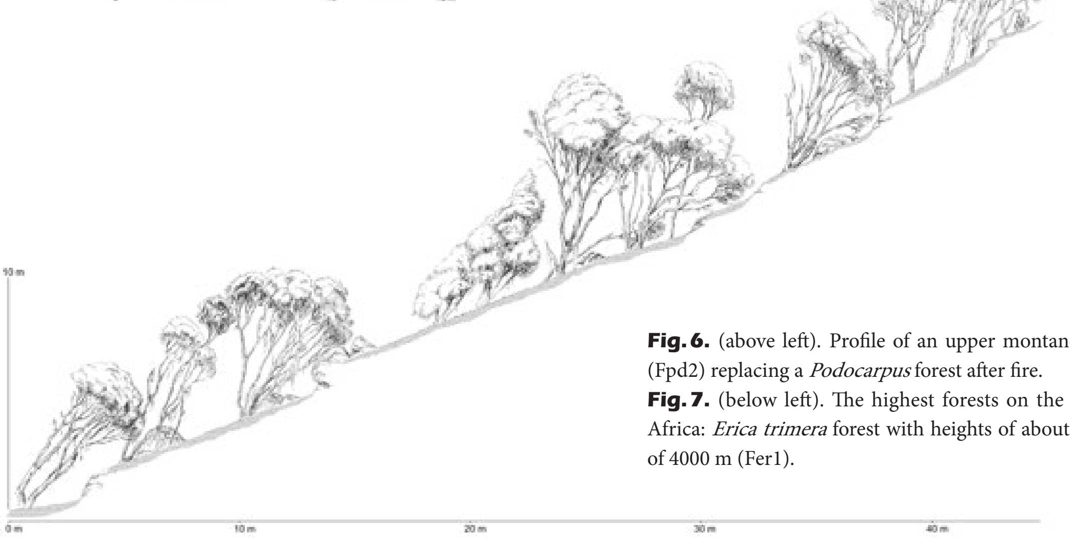


Fig. 6. (above left). Profile of an upper montane *Erica excelsa* forest (Fpd2) replacing a *Podocarpus* forest after fire.

Fig. 7. (below left). The highest forests on the highest mountain of Africa: *Erica trimera* forest with heights of about 10 m at an elevation of 4000 m (Fer1).

Mountains become islands: ecological dangers of increasing land-use in East Africa

by Andreas and Claudia Hemp

The mountains of East Africa are a treasure trove of biodiversity. However, their ecosystems may be at a higher risk than previously realized. Mt Kilimanjaro is turning into an "ecological island". Agriculture and housing construction have eliminated the natural vegetation that used to serve as a bridge to the surrounding area, enabling the diversity of species to develop to its current levels. Neighbouring mountain regions are presumably also being isolated from their surrounding areas.

With a height of almost 6000 m Mt Kilimanjaro is the highest mountain in Africa, and it is located less than 100 km from the 4,600 m high volcano Mt Meru in northern Tanzania. Satellite images show how the strips of land between them changed in the 25 years leading up to the turn of the century. Areas that originally had dense vegetation were forced to make room for the intensive agriculture and residential development of a growing population. Nowadays, Mt Kilimanjaro is almost completely surrounded by large areas that are characterized by the encroachment of human civilization.

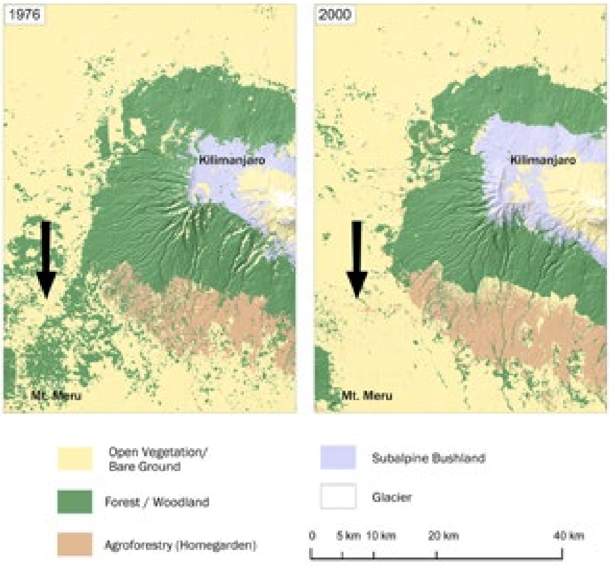
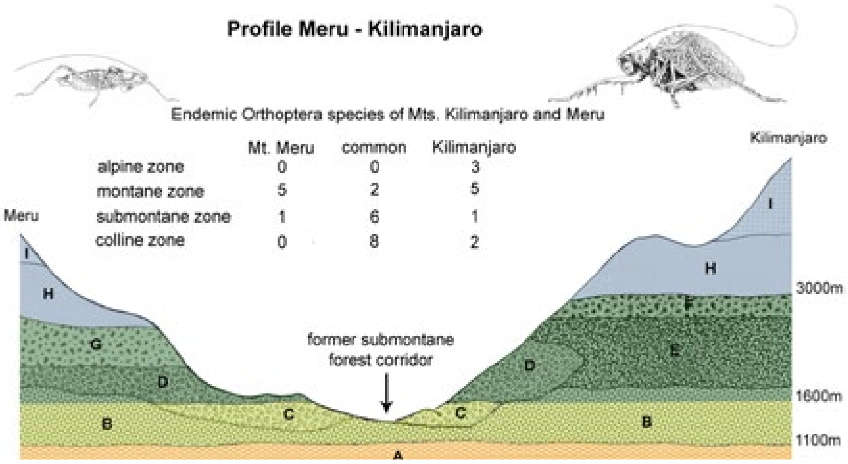


Fig. 1. Disappearing forest corridor between Mt Meru and Mt Kilimanjaro. The maps are a result of a supervised classification of Landsat MSS images taken on 24 January 1976 and Landsat ETM images taken on 29 January and 21 February 2000 (source: USGS/UNEPGRID-Sioux Falls) using the software IDRISI 3.2; left: situation in the year 1976, right: situation in the year 2000. In 1976, remnants and patches of (disturbed) submontane forest and woodlands still connected Mt Meru and Mt Kilimanjaro, whereas in 2000, they were replaced by cultivation. This conversion of natural vegetation on the foothills makes Kilimanjaro an isolated mountain inhibiting migration of forest animals.

Bridges of vegetation promote the diversity of species

In order to investigate the impact this rapid change is having on biodiversity, the environments of grasshoppers at 500 selected sites on Mt Kilimanjaro and Mt Meru were studied. In this investigation, endemic species – species that are only native to this region of East Africa – were of particular interest. An especially high proportion of endemic species was found in the forest areas at lower altitudes shared by these two mountains. This is a clear indication that grasshoppers once used the dense vegetation between the mountains as bridges to spread out in both regions. Most notably, the flightless species relied on this land route.

Conspicuously, there are also a few endemic species that are only found in higher forest areas. Geoscientific findings suggest the answer lies in palaeo-ecological climate changes. Thus, grasshoppers that preferred these climatic conditions settled at the foot of the mountains, travelling by foot via the wooded land route. It was only later, as the temperatures rose and precipitation diminished that they made their way to higher areas. They then no longer had contact to grasshoppers in neighbouring regions. These research findings corroborate the thesis that animal and plant species spread out primarily via bridges of vegetation. In contrast, other ways of spreading over long distances, for instance seed transport via wind or the “air travel“ of individual insects, must have played a subordinate role. All of these prehistoric processes are still reflected in the current diversity of species we encounter in mountainous regions of East Africa, many of which are difficult to reach. The endemic



	Mt. Meru	common	Kilimanjaro
alpine zone	0	0	3
montane zone	5	2	5
submontane zone	1	6	1
colline zone	0	8	2

Fig. 2. Numbers of endemic Orthoptera (shared by both or by one mountain) and their distribution in the elevational belts and vegetation types, displayed in a schematic west–east profile showing the eastern slope of Mt Meru and the western slope of Mt Kilimanjaro.
Orange: colline zone, light green: submontane zone, dark green: montane zone, blue: (sub)alpine zone. (**a**) colline savanna, mainly converted into agriculture; (**b**) agroforestry (homegardens) and partly agriculture in the submontane and lower montane zone; (**c**) submontane *Croton–Calodendrum* forest; (**d**) lower and middle montane *Cassipourea* forest; (**e**) lower and middle montane *Ocotea* forests (only Kilimanjaro); (**f**) upper montane *Podocarpus* forest; (**g**) upper montane *Juniperus* forest; (**h**) subalpine heathlands (*Erica* bush); (**i**) alpine *Helichrysum* cushion vegetation.

species, in particular, help researchers trace the development of natural history.

Grasshoppers as early warning systems for endangered species

If bridges of vegetation between the mountains weaken or vanish altogether, it is not just the mobility of grasshoppers that is affected. Larger animals living in the forest – e.g. antelopes, small mammals, snakes, or chameleons – are at an even higher risk of becoming isolated and thus going extinct in the foreseeable future.
Grasshoppers serve as an early warning system for researchers, signalling these kinds of far-reaching effects for other animal groups that are often difficult to study. However, reliable statements about the ecological interrelationships are only possible after many years of scientifically demanding field studies.

Support for the research from natural history museums

The study, which was funded by the German Research Foundation (DFG), would not have been possible without the support of research institutions in Tanzania and the cooperation of the natural history museums in Nairobi, London, Tervuren (Belgium), Berlin, Madrid, Stockholm, and Vienna. This enabled the researchers to compare their evolutionary and taxonomical findings from their investigations of grasshoppers in Tanzania with the museums‘ insect collections. This study demonstrates the considerable scientific relevance of such natural history collections. The museums offer more than just fascinating insights into the diversity of species and the history of their evolution. They are also crucial for the investigation of ecological interrelationships in times of global anthropogenic changes.

Publication: Andreas Hemp and Claudia Hemp: Broken bridges: The isolation of Kilimanjaro’s ecosystem, Global Change Biology (2018), doi: 10.1111/gcb.14078

Lichen diversity on Mt Kilimanjaro

by Ulla Kaasalainen, Andreas Hemp & Jouko Rikkinen

Lichens are mutualistic symbioses between lichen-forming fungi (mycobionts) and algae and/or cyanobacteria (photobionts). Most lichen mycobionts are specific in their photobiont choice and the local availability of compatible photobionts may limit their ability to disperse into new habitats. Lichens are an important component of the ecosystem and contribute significantly to biodiversity and biomass in many environments. They intercept and retain moisture, provide habitat and food for invertebrates, and contribute fixed nitrogen into the ecosystem, and often their ecological significance is pronounced towards extreme environments.

To provide the first account of lichen symbiont diversity in tropical mountain ecosystems and to elucidate the effects of human induced environmental change to lichen symbiotic organisms, specimens were collected from 65 sample plots situated on five replicate transects along the natural environmental gradient of the southern slope of Kilimanjaro. Sampled ecosystem types ranged from savanna through several forest zones to alpine heath vegetation, including also several ecosystem types disturbed by fire, logging or agriculture.

Fig. 1. Abundant lichen epiphytes (especially *Usnea* spp.) on tree trunks in *Erica* forest. (Photo: Jukka Korpelainen).

Fig. 2. Lichenologist at work among alpine *Helichrysum* vegetation. In such environment, lichens are often a prominent part of the vegetation, growing on rocks and, especially on more sheltered places, also on the ground. (Photo: Jukka Korpelainen).

Our results showed that clear differences existed in lichen biota between different ecosystem types. In more open and especially in the heavily disturbed low-elevation habitats, lichen abundance and diversity seemed to correlate primarily with the presence/absence of woody plants. Lichen taxa characteristic for these drier and warmer habitats included several genera of Physciaceae, certain specific species of Collemataceae, and for example the genus *Candelaria*. The lichens in such environments are often very small in size and grow closely adnate to their substrate.

Within the forest zones, light availability, moisture, and competition with other epiphytes like bryophytes had a clear impact in lichen abundance and species composition, and the species composition often varied also between the canopy and lower vegetation layers. Abundant taxa included for example *Parmotrema*, *Heterodermia*, *Leptogium* and several other cyanobacterial lichen species, *Hypotrachyna*, and *Usnea*. The most prominent lichens were found in *Erica* forest in 3200–4000 m altitude, where abundant epiphytes partly covered most of the other vegetation. Epiphytic taxa included especially *Usnea*, but in addition several foliose genera of Parmeliaceae were common. Additionally, e.g. *Cladonia*, *Peltigera*, and *Stereocaulon* were found on the rocks and ground on the forest floor.

Even higher, above the tree line, lichens comprised a considerable proportion of the vegetation. Growing on rocks, ground, and occasional shrubs, many taxa like *Xanthoparmelia*, *Hypotrachyna*, *Usnea*, *Hypogymnia*, *Cladonia*, and *Stereocaulon* still thrived even in these harsh conditions.

This study was a collaboration of the KiLi Project (Subproject 4) and the Chiesa project, University of Helsinki, Finland.

Acknowledgements: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 705777.

Fig. 1. Plot setup for the sapling inventory.

Natural forest regeneration at Mt Kilimanjaro

by Marion Renner, Andreas Hemp & Markus Fischer

Tropical forests show general broad scale patterns of biomass and diversity distribution. Changes of environmental factors or disturbances, natural as well as anthropogenic ones, can strongly affect the species distributions and thus these patterns. Especially tropical mountains are highly affected by the combined effect of climate change and land-use. With ongoing climate warming the dry and hot foothills of Mt Kilimanjaro might not support woody growth anymore and species might be pushed upwards. Furthermore, former logging and fires at higher elevation as well as ongoing land-use at lower elevation might have changed the abundance and diversity of woody species. However, only looking at the sapling layer holding the smallest and most sensitive stages of a tree`s life shows a glimpse into the future composition. The mismatch of species compositions between different canopy layers may indicate ongoing changes.

To fill this gap we investigated as first comprehensive study in East Africa the regeneration of woody species in six natural and seven anthropogenic disturbed habitat types along the elevational gradient of Mt Kilimanjaro. We recorded all woody stems between 25 and 130 cm in the 20 x 5 m core plots within each of the 65 plots of the KiLi Project. Overall we recorded 4846 small woody stems belonging to 110 species. The formerly logged *Ocotea* forest harboured the highest number of small stems, whereas savanna and lower montane forest harboured the highest number of species. The highest number of stems found on a plot was 602 and the highest number of species 19.

We found woody regeneration in all natural habitat types and on all plots, where woody species occur in higher canopy layers, except 2 subalpine *Erica trimera* plots. The number of small stems showed a hump shape distribution, peaking at mid elevation, and the number of species was decreasing with elevation. As both results are in line with already known patterns at Kilimanjaro, it seems, as climate change might not have shifted yet the overall distribution of woody species.

When comparing the regenerating stems with the higher canopy layers, we found that the sapling layer in the savanna bears up to almost the threefold amount of woody species than the higher canopy layers, however the communities were strongly differing, on some plots by 100%. This might indicate that safe sites for germination and establishment are sporadic and rare and that many stems die due to drought periods and browsing. Therefore, climate change and increased land-use could highly degrade the regeneration potential of the savanna. In contrast, the forest zone showed a lower species number in the sapling than in the higher canopy layers and a lower, however still 30% species turnover to the shrub and tree layer. This might be caused by sporadic recruitment, recruitment lacks of species as well as by the small scale heterogeneity of forests. Only long term observations can reveal clear answers.

Agricultural land-use at lower elevation, namely maize fields, grasslands, homegardens and coffee plantations, reduced the number and diversity of stems dramatically, therefore impeding the natural regeneration. Plots with former disturbance in form of fire and logging showed an increased recruitment of stems and species than natural plots, a proof of still ongoing succession and the change to return to the former state. However, as these differences are in the lowest canopy layer, the recovery to the old growth forest is by far not yet finished after time spans of 30–40 years, which shows the huge and long lasting impact of anthropogenic disturbance in forests.

Fig. 2. Sapling labeling on a natural *Ocotea* plot with plenty of *Ocotea usambarensis* rootsuckers.

Fig. 3. *Rapanea melanophloeos* sapling.

Tropical tree species` response to the combined change of temperature and water availability in a transplantation experiment

by Marion Renner, Andreas Hemp & Markus Fischer

To assess the future of East Africa's forests it is crucial to understand how warming and changing precipitation, the main components of climate change, effect the first steps of a tree`s life. A decrease in temperature or precipitation was mostly shown to reduce and an increase to boost tree growth. However, there is some uncertainty for tropical species, as they might have a more narrow temperature niche than temperate species and live already at their physiological limit. As the plant`s temperature regulation and water household are highly linked, the response to a temperature and water availability change could furthermore constrain or facilitate on each other.

To be able to predict species vulnerability in a wider range, multispecies experiments offer the opportunity to link species responses to species characteristics like leaf traits and the biogeographic origin. To fill the gap in experimental approaches, testing the combined effect of temperature and water availability on tropical African trees, we did a transplant experiment with 31 tree species, native as well as exotic ones to East Africa, at the slopes of

Fig. 1. Savanna garden at 880 m a.s.l. close to Moshi.

Fig. 2. Submontane garden at Kidia 1440 m a.s.l. PhD students Neduvotu Mollel and Marion Renner checking on the tree saplings. In the background scientific garden helper Julieth Mshida responsible for the gardens and also member of the NGO TanzMont. Tree saplings remaining from the experiments of the PhD students were planted by TanzMont in savanna habitats and the nearby Msaranga valley.

Mt Kilimanjaro. We germinated and grew the tree species with collection elevations from 591 – 3026 m a.s.l. in two gardens, one savanna garden (880 m a.s.l.) and one submontane garden (1450 m a.s.l.), kept half of them with natural precipitation and half with additional watering. After 3.5 and 6.5 months we measured mortality and performance.

Germination, mean performance, but also mortality was higher in the hotter savanna garden. Tree species of a wide elevation range grew better in savanna than in montane garden. However, species from very low as well as very high collection elevations grew better in their "home" elevation than in their "away" elevation. Furthermore, a low specific leaf area, which is shown by tough, well coated leaves and represents a careful use of resources, was beneficial for survival and growth in the savanna garden. This might imply that global warming may facilitate the overall seed germination as well as favour species already preadapted to warmer temperatures and with a low specific leaf area. Species from higher elevations, not preadapted to warmer temperatures, and species with a high specific leaf area may be outcompeted. Additional water, however, pushed especially species with high specific leaf area as well as exotic species. Thus, their superiority over indigenous species and species with a low specific leaf area may rise in areas with a precipitation increase.

As many of our study species have a wide distribution range throughout East Africa, where generally little of the forest cover is left, and as temperature is proven to increase, our experiments suggest that forest management in East Africa should consider temperature adapted species.

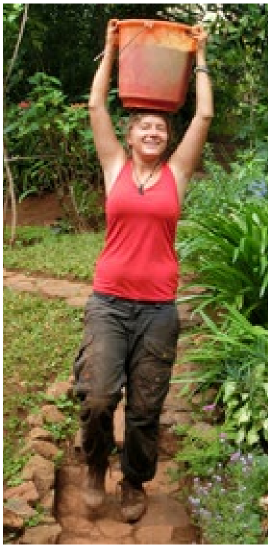


Fig. 3. PhD of SP 4, student Marion Renner, working in the scientific garden Kidia.

Fig. 4. Tree saplings in the scientific garden Kidia 2015 with family and Kichagga name. **A.** *Albizzia gummifera* (Mimosaceae) mlamvíà **B.** *Bersama abyssinica* (Melianthaceae) ira-ndáwà **C.** *Cordia africana* (Boraginaceae) mringà-ríngà´ **D.** *Croton megalocarpus* (Euphorbiaceae) mfuù-fúrù´ **E**. *Euclea racemosa* (Ebenaceae) **F.** *Ficus sur* (Moraceae) kmuyù, mkuyù´ **G.** *Hagenia abyssinica* (Rosewood)(Rosaceae) mwangá`, mlangá` **H.** *Leucaena latisiliqua* (Caesalpiniaceae) **I.** *Newtonia buchananii* (Mimosaceae) mkufí´ **J.** *Podocarpus latifolia* (Podocarpaceae) mtong´òsó` **K.** *Spathodea nilotica* (Bignoniaceae) **L**. *Ziziphus mucronata* (Rhamnaceae).

How will Kilimanjaro's herbaceous flora respond to climate warming?

Lessons from a large transplantation experiment across the savanna and submontane region

by Andreas Ensslin, Neduvoto Mollel, Andreas Hemp & Markus Fischer

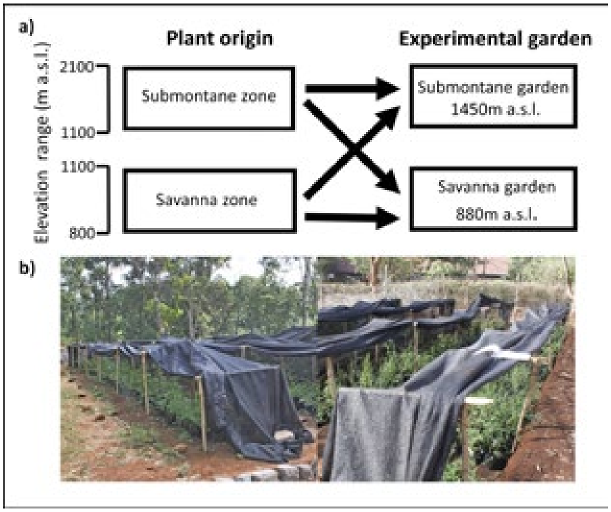


Fig. 1. Experimental design of the transplantation study (a) and pictures of the two experimental gardens (b) in the submontane zone (left) and in the savanna zone (right).

To assess the future development of Kilimanjaro`s vegetation, it is crucial to understand how climate warming affects plant performance across taxa and vegetation zones. The lowest two vegetation zones, i.e. the savanna and the submontane regions, are particularly important, because this is where the local population lives and climate change impacts on the plants may directly affect the people's well-being. To study plant responses to changes in temperature, we compared the survival, growth and reproduction of 116 herbaceous species originating from the savanna and the submontane vegetation zones in two experimental gardens representing the climate of both zones (Fig. 1). Thanks to the multi-species approach, we could get insights into climate change responses across many taxa, but also group the species into different functional groups such as grasses and forbs or natives and exotics, to see whether certain plant groups are more susceptible to temperature changes than others.

For a subset of 15 species, we also investigated whether these species possess genetic variation in fitness-relevant traits and in plasticity of those traits to temperature changes. Genetic variation in traits and in phenotypic plasticity is the basis for allowing organisms to adapt to changing environmental conditions. Hence, it is one of the fundamental questions in global change research as it provides the information whether plants have the necessary prerequisites to evolutionary adapt to environmental change.

In 2011 and 2012, we reciprocally transplanted all species simultaneously to the submontane and the savanna garden, so every species was grown in a "home" garden of its own elevational zone and in an "away" garden in the other zone (Fig. 1a). For the 15 species of the genetic variation study, we grew several progeny per mother plant in both gardens. This half-sib family design allowed us to study genetic variation in traits and in plasticities of these traits to transplantation. We measured plant growth and reproduction for each species at the peak of development when it produced the first ripe seeds. We found that herbaceous plants from the lower montane climate grew considerably less good and produced less flowers in the 5 degrees hotter savanna garden than in their "home" submontane garden (Fig. 3). This clearly showed that submontane plants will have difficulties if future temperatures in the submontane region rise to those of the current savanna climate in the next century, a projection, which still lies within range of current climate change scenarios. Moreover, we found that savanna species grew very well under both, savanna and submontane temperatures (Fig. 3). This indicates that herbaceous savanna plants do not grow in the savanna because they are adapted to the savanna temperatures, but rather because they are pushed into the more stressful savanna climate, possibly due to competitive disadvantages or a lack of dispersal. We also found that grasses responded differently to temperature changes than forbs, and that exotic plants responded differently than native plants. These differences show the importance of considering

Fig. 2. Different phases of the first transplantation experiment.
a) Levelling and digging rows for the savanna garden in Moshi in 2011,
b) distribution of grow bags filled with a special sand/soil mixture,
c) careful watering of the young seedlings and
d) measuring the plants at maturity.

functional groups in climate change studies, and suggest that warming could result in strong changes of vegetation composition on Kilimanjaro in the future (for more information see Ensslin *et al.* 2017). For the 15 species with the sibling design, we found evidence for genetic variation in fitness relevant traits such as plant height, biomass and flower production, and leaf area. Moreover, we also found genetic variation in plasticity to temperature change in some of the traits. We concluded from this study that common plants in the lower parts of Kilimanjaro possess the preconditions to evolutionary adapt to climate change. However, whether plants will finally adapt or not will also depend on other factors such as precipitation and land-use change, and biotic interactions with other plants (competition) or trophic levels (herbivory).

Taken together, our experiment shows that temperature rise will have serious consequences on the herbaceous vegetation composition of Kilimanjaro's submontane and savanna belt, but also that there is a chance that some plants adapt to the changing conditions. Attenuating the negative impacts of climate change while allowing the species to adapt will be a great challenge in the future.

The results of the experiment were published in two articles:

Ensslin, A., Fischer, M. 2015. Variation in life-history traits and their plasticities to elevational transplantation among seed families suggests potential for adaptive evolution of 15 tropical species to climate change. American Journal of Botany 102, 1371–1379. DOI: 10.3732/ajb.1400518.

Ensslin, A., Mollel, N.P., Hemp, A., Fischer, M. 2017. Elevational transplantation suggests different responses of African submontane and savanna plants to climate warming. Journal of Ecology 1–10. DOI: 10.1111/1365–2745.12842

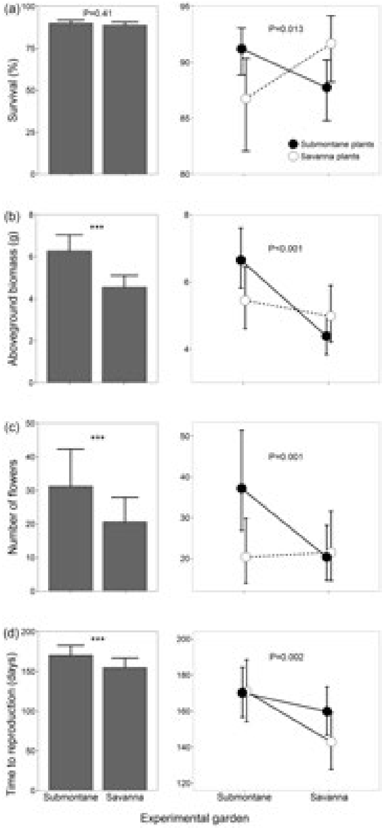


Fig. 3. Responses of submontane and savanna plants to transplantation to different elevations. Main effect of experimental garden (left panels) and its interaction with plant origin (right panel) where 65 submontane plant species (filled circles) and 36 savanna plant species (open circles) were grown in one submontane and one savanna experimental garden. In the right panel, solid lines indicate significant differences in the performance of species per origin between the two gardens, while dashed lines indicate the absence of such significant differences. (a) Plant survival, (b) above-ground biomass, (c) number of flowers and (d) time to reproduction. P-values refer to main effects and two-way interactions.

Assessing the structure and complexity of Kilimanjaro's vegetation

by Gemma Rutten, Andreas Ensslin, Andreas Hemp & Markus Fischer

Complex vegetation structure can facilitate biodiversity and ecosystem services. Therefore, measures of vegetation structure can serve as indicators in ecosystem management. However, many structural measures are laborious and require expert-knowledge. We used consistent and convenient measures to assess the complexity of Kilimanjaro's vegetation over the whole elevational gradient from 866–4550 m a.s.l. Additionally, we compared (human) modified habitats, including maize fields, homegardens, grasslands, commercial coffee farms and logged and burned forests, with natural habitats along the elevational gradient. Vertical vegetation structure (assessed as number, width and density of vegetation layers, maximum canopy height, leaf area index and vegetation cover) displayed a unimodal elevation pattern, peaking at intermediate elevations in montane forests, whereas horizontal structure (assessed as coefficient of variation of number, width and density of vegetation layers, maximum canopy height, leaf area index and vegetation cover) was lowest at intermediate altitudes. Overall, vertical structure was consistently lower in modified than in natural habitat types, whereas horizontal structure was inconsistently different in modified than in natural habitat types, depending on the specific structural measure and habitat type. Our study shows how vertical and horizontal vegetation structure can be assessed efficiently for various habitat types in tropical mountain regions, and we suggest applying this as a tool for informing future biodiversity and ecosystem service studies.

This study was published as:
Gemma Rutten, Andreas Ensslin Andreas Hemp, and Markus Fischer. "Vertical and Horizontal Vegetation Structure across Natural and Modified Habitat Types at Mount Kilimanjaro." PLoS ONE 10, no. 9 (2015a): 1–15. doi:10.1371/journal.pone.0138822.

Fig. 1. Gemma Rutten recording vegetation structure at predefined points in one of the homegarden plots.

Quantifying aboveground biomass along Kilimanjaro's elevational gradient, and how it changes with land-use

by Andreas Ensslin, Gemma Rutten, Ulf Pommer, Andreas Hemp & Markus Fischer

The protection and sustainable management of forest carbon stocks, particularly in the tropics, is a key factor in the management and mitigation of global change. However, knowledge of how the carbon stocks of tropical ecosystems vary with land-use and elevation is limited, and how much carbon is stored in Kilimanjaro's various natural and managed ecosystems has not been properly assessed yet. We studied aboveground biomass of trees, shrubs and herbs in eleven important habitat types over the whole elevational gradient (866 m to 4550 m) on Kilimanjaro, including natural and (human-)modified habitats. We used height, diameter at breast height and wood density measurements gathered in the tree inventory, and pantropical allometric equations to estimate tree and shrub biomass and destructive sampling to estimate herbaceous biomass. We found a unimodal pattern of tree biomass over elevation, peaking in the montane region at 2000 – 2500 m with ~350 Mg ha^{-1}. Shrub biomass declined with increasing elevation, ranging from ~7 Mg ha^{-1} at around 900 m to zero above 4000 m. Herbaceous biomass followed the inverse hump-shaped pattern with lowest biomass at mid-elevations (~1 Mg ha^{-1}) and higher biomass in savannas (~3 Mg ha^{-1}) and alpine vegetation (~9 Mg ha^{-1}). Anthropogenic influence in the lower montane zone resulted in dramatic biomass decreases mainly due to deforestation. In the savanna zone, where maize cultivation strongly increased herbaceous biomass compared with savannas, but decreased woody biomass, total biomass was not significantly affected (Fig. 2). Our estimates of biomass stocks over a wide range of habitat types highlight the importance of tropical montane forest as an important carbon stock. Moreover, they demonstrate the large release of carbon following human land-use, particularly when tropical rainforest is converted to farmland or grassland for food and animal fodder production (Fig. 2b). To maintain carbon stocks on Kilimanjaro, it is crucial to secure the natural rainforest in the submontane zone inside and more importantly, outside the national park and prevent further conversion of savanna woodlands to agricultural farmland in the savanna zone.

Fig. 1. Andreas Ensslin and Jubilate Maruchu measuring tree height in the course of the tree inventory for the estimation of tree biomass and carbon storage in the submontane rainforest.

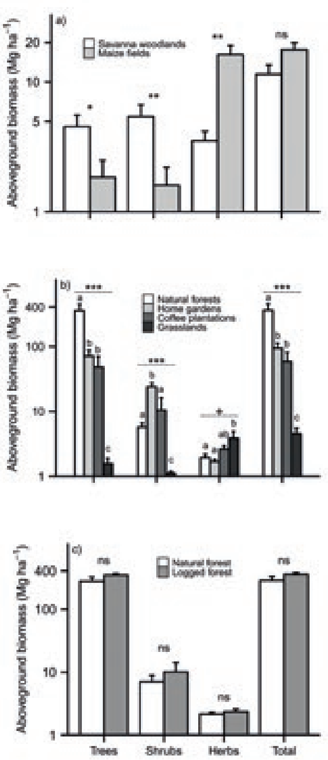


Fig. 2. Aboveground biomass (measured in tons per hectare=Mg ha^{-1}) of various natural habitats compared with the major land-use types in the same elevational zone. a) Savanna zone, b) submontane zone and c) montane zone. For more information, see Ensslin *et al.* 2015 Ecosphere.

This study was published as:
Ensslin, Andreas, Gemma Rutten, Ulf Pommer, Reiner Zimmermann, Andreas Hemp, and Markus Fischer. "Effects of Elevation and Land-Use on the Biomass of Trees, Shrubs and Herbs at Mount Kilimanjaro." Ecosphere 6, no. 3 (2015): art45–art45. doi:10.1890/ES14–00492.1.

Effects of selective logging on tree population structure in the montane *Ocotea*-forest

by Gemma Rutten, Andreas Ensslin, Andreas Hemp & Markus Fischer

The montane forests of Mt Kilimanjaro in Tanzania have been subjected to a long history of selective logging. However, since 1984 selective logging is prohibited. Today, these forests allow us to evaluate the long-term effects of selective logging.

Therefore, we mapped the height and diameter at breast height (DBH) of all trees >10 cm DBH on 10 sites of 0.25 ha. Five sites represented non-logged forests, another five selectively logged forests. We tested whether forests were affected at least 30 years after selective logging in terms of their vegetation structure and tree diversity. To address potential mechanisms, we also compared tree densities of different species guilds, including disturbance-indicator species, late-successional species and main timber species. Furthermore, we specifically compared the community size distributions of selectively logged and non-logged forests, first across all species and then for the most important timber species, *Ocotea usambarensis*, alone.

Selectively logged forests showed a higher overall stem density, higher relative abundances of small trees (<50 cm DBH) and higher stem densities, of the small size class, of late-successional tree species than non-logged forests. For *O. usambarensis*, the selectively logged sites still harboured higher relative abundances of small trees and lower relative abundances of harvestable trees. Together, our results suggest a generally greater regeneration, especially the higher relative abundance of small *O. usambarensis*-stems in selectively logged forests appears promising for future forest recovery.

This study was published as:

Rutten, Gemma, Andreas Ensslin, Andreas Hemp, and Markus Fischer. "Forest Structure and Composition of Previously Selectively Logged and Non-Logged Montane Forests at Mt Kilimanjaro." Forest Ecology and Management 337 (2015b): 61–66. doi:10.1016/j.foreco.2014.10.036.

Fig. 1. Pictures of a natural montane *Ocotea*-forest (a) and a formerly logged *Ocotea*-forest (b). The higher occurrence of small diameter trees in the formerly logged forest is clearly visible.

Fig. 2. Andreas Ensslin and Gemma Rutten, PhD students of SP4 during phase 1, off into the field...

Phylogenetic diversity analyses reveal contrasting responses of herb, shrub, tree, liana and epiphyte tropical communities to human disturbance

by Rafael Molina-Venegas, Markus Fischer &
Andreas Hemp

Anthropogenic disturbance has been recognized as one of the most pervasive factors affecting biodiversity in tropical ecosystems. Besides loss of species, human disturbance can also affect other axis of biodiversity. For example, there is increasing evidence that anthropogenic disturbance can reduce phylogenetic diversity in the communities (i.e. the coexistence of multiple evolutionary lineages) due to environmental filtering of disturbance-intolerant lineages. If we assume that closely related species share combinations of traits that modulate their response to disturbance pressures (i.e. they respond similarly to disturbance), then lineages that are unsuitable to persist under high disturbance levels may be excluded from the communities, and therefore phylogenetic diversity would be drastically reduced (Fig. 1). Importantly, preserving high levels of phylogenetic diversity may be critical to maintaining high levels of ecosystem functioning if the individual functions are particularly promoted by specific lineages. For example, species in the Fabaceae are well-known for their ecological role in nitrogen fixation.

Although phylogenetic diversity – human-disturbance relationships have been already explored in tropical ecosystems, most studies have focused on the angiosperm tree flora, while the phylogenetic diversity of other vegetation strata (i.e. herbaceous layer, shrubs, lianas and epiphytes) remains largely unexplored. Epiphytes (i.e. plants rooting on other plants rather than on the ground) can constitute up to 50% of the total vascular flora in some tropical forests, and they are of great importance for ecosystem nutrient dynamics. Moreover, lianas constitute ~25% of woody stem density in tropical forest, and can contribute significantly to carbon storage). Importantly, these functional groups are likely to experience environmental harshness differentially, and thus they could show contrasting responses to the same anthropogenic stressors.

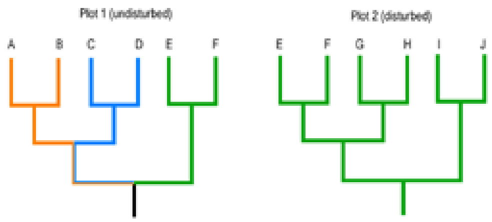


Fig. 1. Conceptual model of the relationship between phylogenetic diversity, ecosystem functioning and disturbance. The figures represent the evolutionary relationships among six co-occurring species in undisturbed (left-side) and disturbed plots (right-side) respectively. The species co-occurring in the undisturbed plot belong to three different lineages (different colours, and each lineage is assumed to provide a different ecosystem function (also represented by different colours). Note that closely related species (e.g. A and B) provide the same function, this is, we are assuming they are functionally redundant. The "orange" and "blue" lineages are defined by disturbance-intolerant species, whereas species of the "green" lineage can tolerate some degree of disturbance. Under human disturbance (plot 2), species A, B, C and D are excluded, and only species that belong to the same disturbance-tolerant lineage can eenter the community and persist (species G, H, I and J would not occur in plot 1 because they are, for example, weak competitors under non-disturbed conditions). Note that despite both plots having the same number of species, phylogenetic diversity is lower under human disturbance (plot 2), and therefore ecosystem functioning is reduced (all species in plot 2 are functionally redundant).

Here, we focus on tropical plant communities at Mt Kilimanjaro (Tanzania) to explore changes in phylogenetic diversity (i.e. mean phylogenetic distance among all species within sampling units, MPD) of vegetation strata along a human disturbance gradient. Second, we develop an extension of the MPD index (MPDc) that allows to elucidate whether phylogenetic structure values are due to the balanced contribution of all lineages in the communities (symmetric phylogenetic diversity) rather than few long-branched lineages with disproportionate influence (asymmetric phylogenetic diversity).

The index represents a way out of a long-standing issue in the eco-phylogenetic literature, this is, the spurious detection of high phylogenetic diversity levels due to the disproportionate effect of a few long-branched lineages

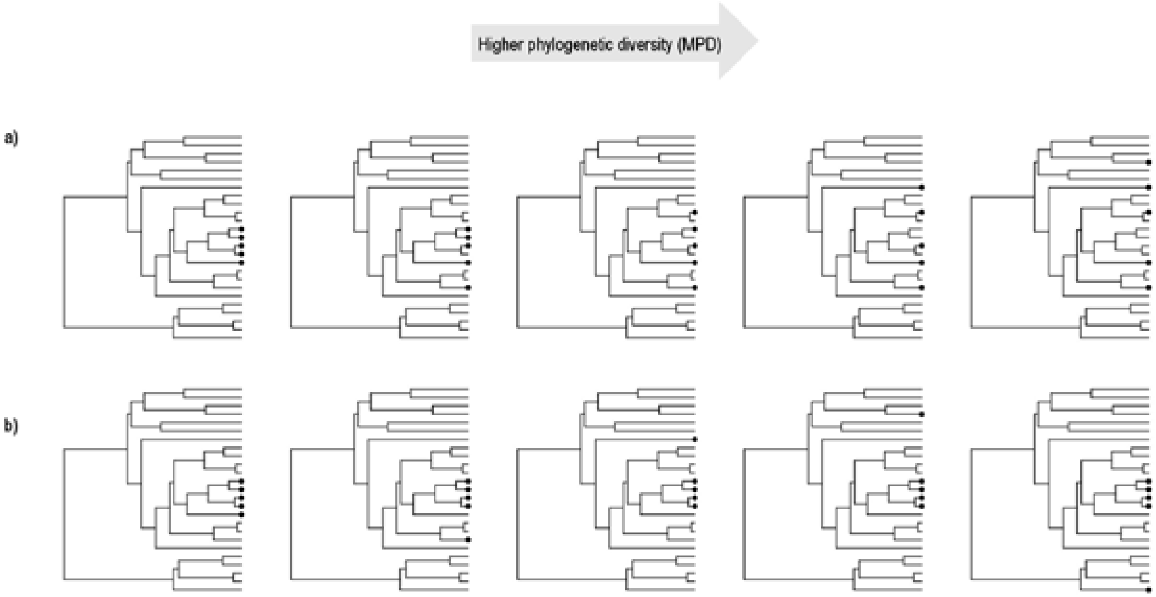


Fig. 2. The effect of long evolutionary branches on phylogenetic diversity estimations (i.e. mean phylogenetic distance among species within communities, MPD). Figures (a) and (b) represent two different sets of communities (N = 5 species per community, n = 5 communities per set) ranked from left to right on increasing order of phylogenetic diversity. In the first scenario (a), the increase in phylogenetic diversity is due to the progressive accumulation of lineages (i.e. symmetrical increase in phylogenetic diversity). In the second scenario (b), the increase in phylogenetic diversity is simply due to the effect of one single species that is disproportionately contributing to the metric (i.e. asymmetrical increase in phylogenetic diversity).

rather than the balanced contribution of multiple lineages (Fig. 2).

We used vegetation surveys conducted across 60 plots located on the southern slope of Kilimanjaro. We recorded all native and naturalized species of vascular plants up to 1 m (herbaceous layer), between 1 – 10 m (shrub layer) and > 10 m (tree canopy layer). Climbing plants reaching into the shrub and tree layers (i.e. lianas) and epiphytic plants were treated as two additional layers, respectively. The abundance of each species within layers was estimated using the Braun-Blanquet scale. After the sampling, we only considered those plots where at least two species occurred in each vegetation stratum (N = 28 plots, n = 5 strata per plot). A total of 379 species of vascular plants were recorded across the selected plots. Anthropogenic disturbance was estimated for each plot as a continuous composite metric which includes the effect of biomass removal, input of chemicals and landscape composition in the surrounding area of the plots. In order to estimate phylogenetic diversity, we built a species-level time-calibrated molecular phylogeny including all sampled species, and used either MPD (a commonly used metric to estimate phylogenetic diversity) and MPDc (this research) metrics.

In accordance with previous findings, all vegetation strata showed an increase in evolutionary relatedness (i.e. lower MPD values) with disturbance (Fig. 3). However, a more nuanced analysis of phylogenetic structure using MPDc revealed contrasting responses across vegetation layers. The MPDc analyses showed that the phylogenetic diver-

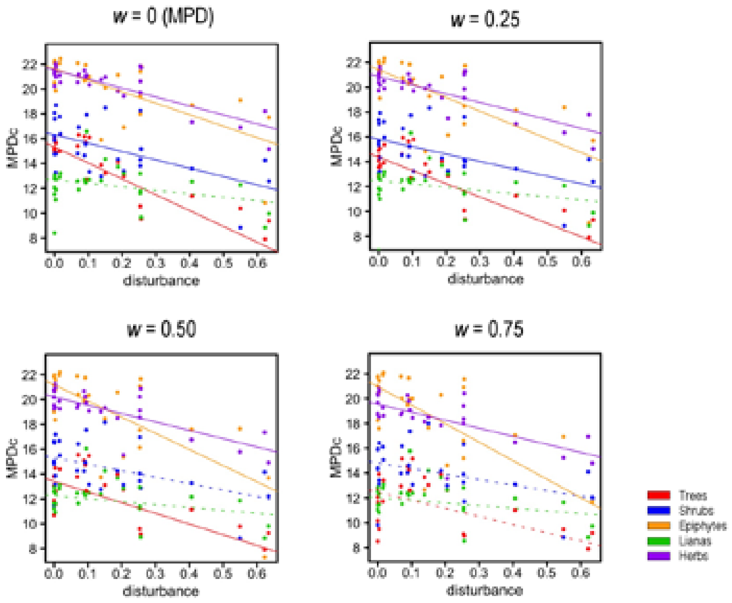


Fig. 3. Relationship between phylogenetic diversity (MPDc, y-axis) of vegetation strata and human disturbance on Kilimanjaro. The higher the value of MPDc, the higher the phylogenetic diversity. The parameter w represents a penalty score for long-branched lineages that is set by the user prior to calculating phylogenetic diversity (the higher the value of w, the lower the influence of long-branched lineages in phylogenetic diversity estimations). When w = 0, MPDc equates MPD (top-left panel). Dashed lines represent non-significant relationships. Note that all strata show a negative relationship between phylogenetic diversity and disturbance when using MPD only (except for lianas, that showed a non-significant relationship in any case). However, as the parameter w is set to higher values, the relationships become steeper for epiphytes and shallower for trees and shrubs. The slope of the relationship between phylogenetic diversity and disturbance for herbs and lianas remained unchanged irrespective of the parameter w, meaning that in these cases all lineages are equally contributing to phylogenetic diversity.

sity of epiphytes was asymmetrically enhanced in highly disturbed plots (due to the effect of a few long-branched lineages that are over-contributing to phylogenetic diversity), thus revealing a drastic reduction in (symmetric) phylogenetic diversity with disturbance than that detected with MPD only (Fig. 3).

The ubiquity of a few generalist epiphyte fern species in the study area such as *Asplenium aethiopicum*, *Pleopeltis macrocarpa* or *Lepisorus excavatus* may explain this “buffering effect”, as these species are subtended by long evolutionary branches (see Fig. 2).

In contrast, the phylogenetic diversity of trees and shrubs was asymmetrically enhanced in undisturbed communities, suggesting a less pronounced decline in (symmetric) phylogenetic diversity than that detected by MPD analyses only. This is, the presence of long-branched lineages of trees and shrubs such as *Podocarpus* in some undisturbed communities makes the decline in phylogenetic diversity more abrupt than it actually is (Fig. 3).

Our results suggest that different vegetation strata experienced environmental harshness differently, as they showed contrasting responses (in terms of phylogenetic diversity) to the same anthropogenic stressors. However, this pattern only emerged after the analyses using our MPDc index, which suggests that a more nuanced consideration of phylogenetic diversity is required in the ecological literature.

Usable wild plant species in relation to elevation and land-use at Mt Kilimanjaro, Tanzania

by Neduvoto Piniel Mollel, Markus Fischer & Andreas Hemp

The impending loss of knowledge about wild useful plants is paralleled by increasing land-use intensification and land cover changes destroying those natural habitats where these plants occur. Thus, it must be feared that this knowledge will fall into oblivion in the near future. This study not only complements previous ethnobotanical studies but also highlights consequences of such global change trends on human welfare and intends to deliver arguments for nature conservation based on traditional plant usage.

The huge gradient of such parameters at Kilimanjaro ranging from hot and dry savanna at the foothills, to montane rain forest and alpine heath lands and covering a high variety of human-impacted habitats at different elevations offers an ideal opportunity for addressing the effect of elevation and anthropogenic impacts on usable plants. For all 962 species occurring in the 60 study plots we assessed whether they were usable for humans and if so, for which purpose (six categories of usage were differentiated: traditional medicine, cattle forage, construction material, food, fuel-wood and shading/ornamental usage). The usable species were calculated for each plot, in total and per category of usage.

Altogether, 563 of the 962 species recorded in all study plots were known to be usable by local people. These species belonged to 346 genera and 119 families. The most represented family across all categories for usage were the Poaceae (75 species), followed by the Fabaceae (55 species), Asteraceae (42 species), Rubiaceae (28 species), Euphorbiaceae (20 species), Lamiaceae (18 species), Aspleniaceae (15 species), Acanthaceae and Cyperaceae (each 13 species). 110 further families were represented by less than 10 species, among them 45 families by just one species.

Of all 563 usable species 385 or 68% belonged to the category of traditional medicine. The second most frequent category was use for forage with 324 (57.5%) species. 112 species (19.9%) were for fuel either as firewood and or charcoal. 103 species (18.3%) were material for construction and making tools. 89 plant species (15.8%) were edible while the smallest group consisted of 38 species (6.7%) that were either preferred as shade trees in coffee and banana gardens or as ornamentals around homesteads. The proportions of usable plant species per plot followed a strong quadratic relationship with elevation forming an unimodal pattern peaking in the lower to middle zones of the mountain (F2,27 = 70.1, R2 = 0.84, P < 0.001; peak at 1900 m a.s.l.; Fig. 1).

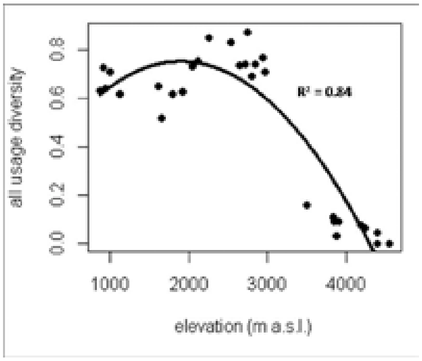


Fig. 1. Proportion of species of any usage category for the 30 plots in natural habitats along the elevational gradient at Mt Kilimanjaro: F2,27 = 70.1, ***P < 0.001. The fitted line represents the significant quadratic function. R2 indicates the variation explainable.

The proportion of useful species was highest between 1000 to 2800 m a.s.l. for all categories but decreased higher up in a linear or quadratic manner (Fig. 1).

The observed quadratic hump-shaped pattern around 1000 to 2800 m a.s.l. suggests that vegetation zones at this elevation have a higher diversity of useful plants species and/or that the Chagga avoided formerly the lower and higher elevations. The decreasing share of useful species with increasing elevation above about 1900 m might partly simply be a result of the rising difficulty in reaching higher elevations and the protection of all habitats above the lower forest border as national park.

Human-influenced habitats had higher proportions of useful species for all usage categories, except for construction and fuel-wood usage (Fig. 2) which were higher in natural savanna and lower montane forest than in used habitats at these elevations.

Given the high proportions of usable wild species we proposed that preserving the biodiversity of Kilimanjaro ecosystems is indispensable for maintaining the diversity of useful plants species for the local people who rely on it for food, sustainable access to medicinal, fuel, construction and forage material.

Fig. 2. Savanna tree used for bee forage and for fuel as firewood and charcoal.

Fig. 4 & 5. Neduvoto Mollel participating in the documentary of ARTE (see KiLi Project and the media) where her project was highlighted.

Fig. 3. Women collecting various grass species for cattle forage at the lower montane elevational zone.

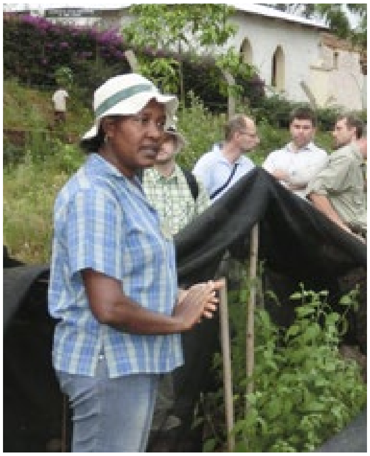


Fig. 6. Nedu Mollel, PhD student of SP4 explaining her garden experiment to a group of scientists.

Land-use / land cover mapping of the Kilimanjaro savanna ecosystem

by Pekka Hurskainen, Hari Adhikari & Andreas Hemp

Classifying land-use / land cover (LULC) with sufficient accuracy in heterogeneous environments characterized by disturbed ecosystems and extensive human-induced LULC change can be challenging using only satellite images. Inclusion of features from auxiliary GIS datasets in classification models to improve classification accuracy has been a standard method since the 1980s, but until recent years, auxiliary datasets of reasonable quality, accuracy and resolution have been scarce on a global scale, especially in sub-Saharan Africa. We wanted to test whether new global and freely available datasets can improve classification accuracy by including them as additional explanatory features in Random Forest (RF) LULC classification models (Table 1). Features tested included topographic features from Alos World 3D Digital Elevation Model, population features from WorldPop and Global Urban Footprint, soil features from SoilGrids, canopy cover from Global Tree Canopy Cover, distance to watercourses from OpenStreetMap and statistical seasonal features from Landsat-8 time series. The baseline classification model, to which the other models were compared, consisted of only spectral and texture features from Formosat-2 satellite images of 2012 with 8-meter spatial resolution.

The study area, 1300 km^2 in size, is located on the southern slopes of Mt Kilimanjaro in Tanzania (Fig. 2). It is characterized by a heterogeneous mosaic of disturbed savanna vegetation, croplands and built-up areas. We used a total of 1370 ground reference points, which consisted of detailed vegetation survey plots, points verified in the field without vegetation survey, and points collected from high-resolution satellite images. These points were randomly split to be used for training the RF classifier algorithms (70%) and to validate the results (30%). Six different classification models with different sets of features were used (Table 1). To account for the variability of random forest predictions, we iterated the algorithm 50 times for each model.

Table 1. Details of the RF classification models.

Model	No. of features	Type of features included
M1	39	Spectral and texture features from Formosat-2 satellite images
M2	43	All features from M1 and population, tree cover and distance to watercourses features
M3	46	All features from M1 and topographic features
M4	58	All features from M1 and soil features
M5	144	All features from M1 and statistical seasonal features
M6	174	All features from M1-M5

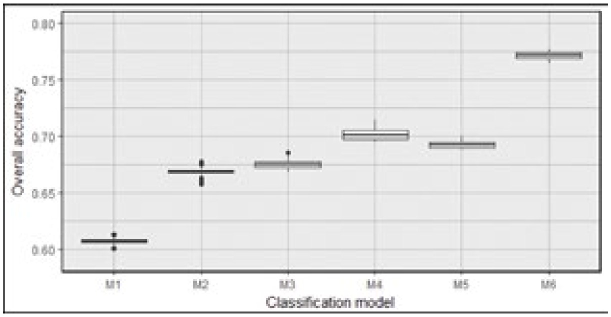


Fig. 1. Comparison of overall classification accuracy of the baseline model (M1) and models with auxiliary features (M2–M6). Boxplots depict the variation of overall accuracy over 50 iterations of each RF model.

Our results show that inclusion of auxiliary variables from freely available global GIS-datasets can significantly improve classification accuracy (Fig. 1). The baseline model M1 gave only a moderate median OA of 60.7%. Inclusion of auxiliary features in the models M2–M5, however, increased median OA between 6.1 and 9.5 percentage points. The best overall accuracy, 77.2%, an improvement of 16.5 percentage points to the baseline, was achieved with the M6, which included all possible features. Figure 2 shows a subset of the classification result with M6.

From these results we conclude that inclusion of freely available global auxiliary datasets can significantly improve classification accuracy in heterogeneous savanna ecosystems with the aid of a sufficiently large ground reference dataset.

In other words, further spatial information about local topography, soil characteristics, settlement patterns and vegetation phenology can help to differentiate and classify land-use / land cover types with better accuracy. Bearing in mind that the auxiliary datasets tested in this study are freely available from the internet for any geographical area in the world, their usefulness in improving classifications of complex heterogeneous ecosystems especially in developing countries should be further investigated.

This study is a collaboration of the KiLi Project (Subproject 4) and the Department of Geosciences and Geography, University of Helsinki, Finland.

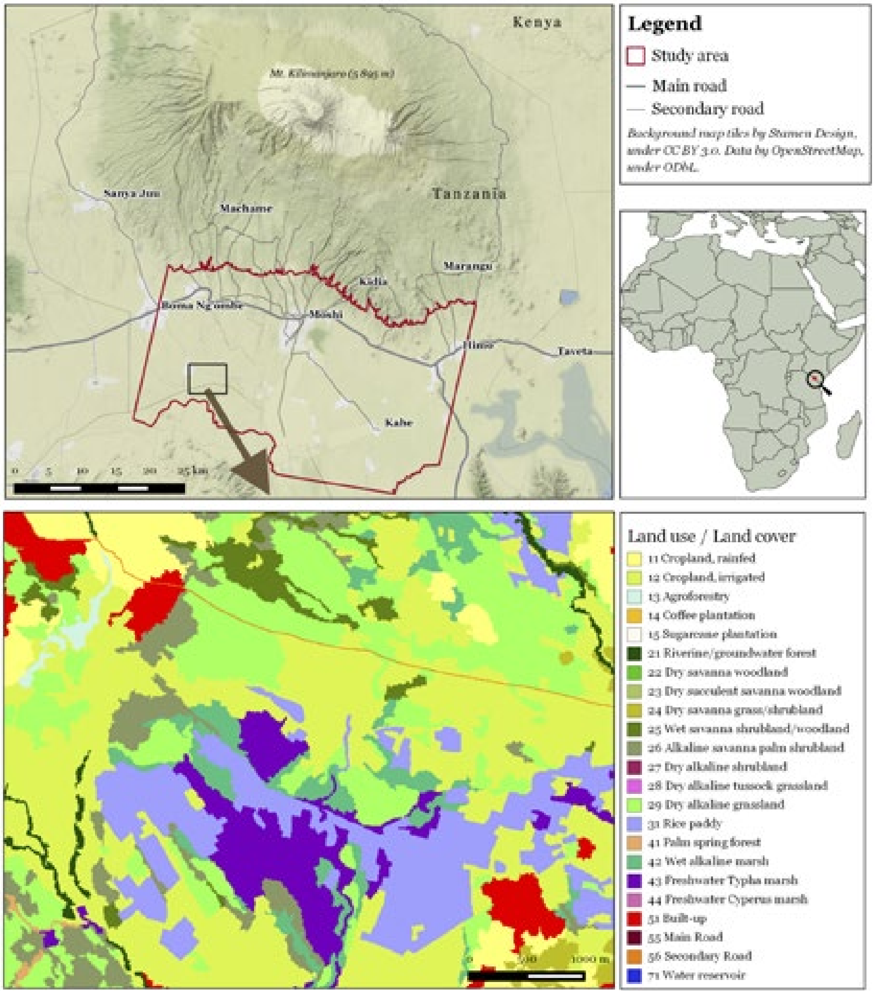
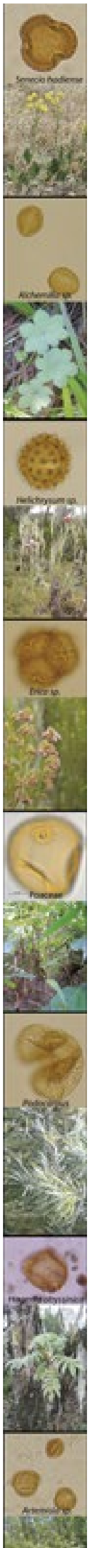


Fig. 2. Subset of the LU/LC classification using the M6 model with all possible auxiliary features.

Fig. 3. PhD student Pekka Hurskainen.



Studies on late Quaternary environmental dynamics (vegetation, biodiversity, climate, soils, fire and human impact) on Mt Kilimanjaro (associate project 1)

by Lisa Schüler, Andreas Hemp &
Hermann Behling

The Tropics are currently the region most influenced by the rapid population growth and the profound changes in land-use. Tropical montane forests represent important biodiversity resources for conservation policies and are crucial for providing many services for quickly growing local human populations. One of the most important resources provided by tropical montane forests is fresh water. Such conditions are typical for East African mountains such as Mt Kilimanjaro, where the montane and subalpine forest have a high potential of collecting precipitation and cloud water. Rising temperatures and decreasing precipitation have changed the hydrology on Mt Kilimanjaro causing severe water shortfall for the Chagga population inhabiting the savannas at the foot of the mountain. Obviously, this lack of water supply together with temperature rise and increased human activities on the mountain has also a major impact on the ecosystems. These profound changes in the environment give rise to many controversial discussions about past, present but also future climate change.

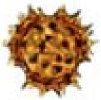
The past is the key to the future

For understanding the ecosystems functioning today we need to investigate past ecosystems and their evolution in a changing environment. Only once we understand the state and dynamics of past ecosystems under certain past climate conditions we will be able to make any reliable predictions concerning their stability or dynamics under different climate change scenarios of the future. Furthermore, this knowledge will allow for a more refined and comprehensive prediction of future changes in biodiversity and biogeographical patterns.

What has pollen got to do with it?

In this project our understanding of vegetation in the past comes mainly from the examination of fossil pollen and spores found in sedimentary records. Pollen is a fine powdery substance comprising pollen grains which are produced by male seed plants for the purpose of reproduction. This fact allows to reconstruct the vegetation from fossil pollen. The potential for fossil pollen to provide an insight into past vegetation change on a landscape scale is hence used to understand changes in vegetation and biodiversity patterns as well as to address conservation issues.

How does it work?



Sediment cores and pollen traps are collected in the field and chemically prepared in the lab to extract pollen and spores. These extracted samples are subsequently transferred to slides and identified and counted under a light microscope.

Where and how did we work?

We investigated soil profiles at several sites at different altitudes on the southern and northern slopes on Mt Kilimanjaro. The sample material was obtained by either coring into wet swamp sediment or by digging soil profiles and taking cores directly from there. Based on the different sites on Mt Kilimanjaro it was possible to reconstruct vegetation and climate dynamics back into the last Glacial.

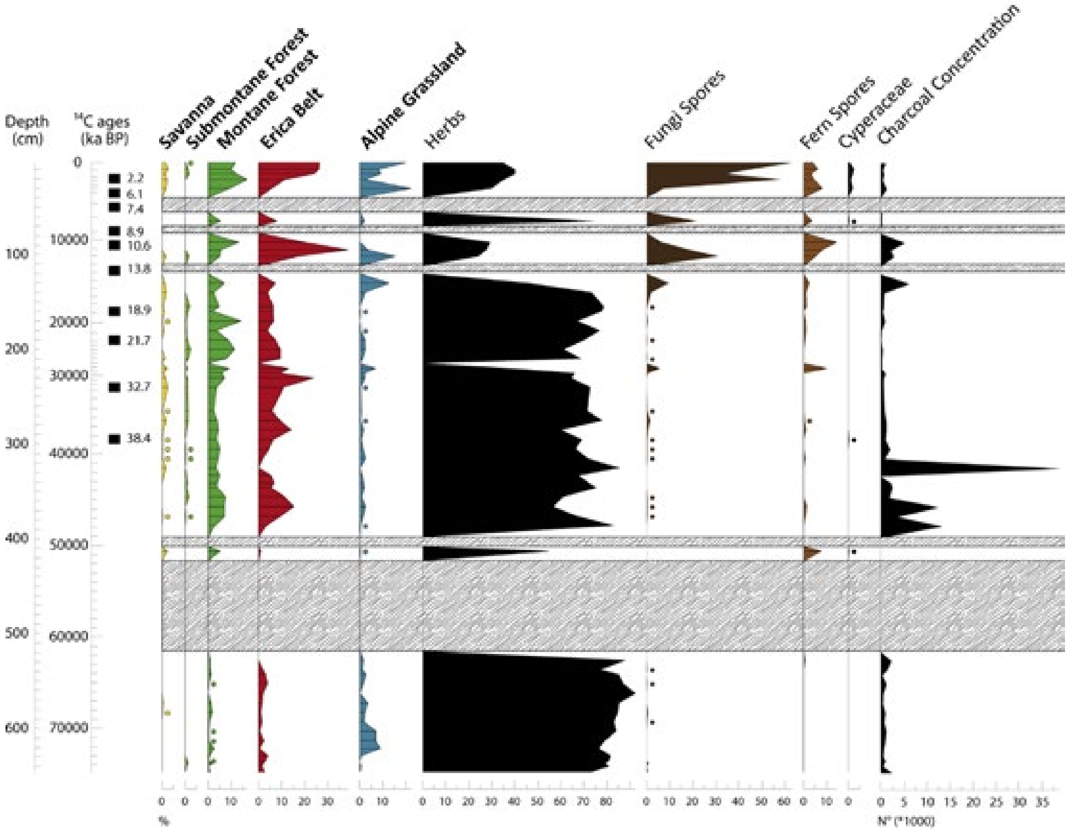


Fig. 1. Summary percentage pollen diagram of pollen and spore taxa as well as charcoal concentration of Maundi crater. Grey shaded areas indicate samples with no pollen content. The age scale is given in years before present (BP).

Vegetation, climate and fire-dynamics inferred from the Maundi Crater and Weru Weru pollen record from Mt Kilimanjaro

The study on Maundi crater provides first palynological data extending back into the early last Glacial (~90,000 years ago) and therefore presents one of the longest terrestrial pollen records in East Africa covering almost a full glacial-interglacial cycle of vegetation and climate history. The Weru Weru study site is in the montane forest at an elevation of 2650 m on the southern slope of Mt Kilimanjaro. This pollen and sediment record of past vegetation and climate dynamics in tropical East Africa extends back to about 50,000 years ago. The reconstructions reveal major shifts in the upper vegetation zones of Mt Kilimanjaro during the last glacial period. The open alpine vegetation was replaced by subalpine ericaceous vegetation and montane forest, which represents an elevational shift of vegetation belts of about 1100 m. During cold and dry periods like the Last Glacial Maximum (LGM) 23,000 to 19,000 years ago, the upper treeline descended by about 1000 m.

Persisting montane forest around the Maundi crater as well as the Weru Weru site suggests only a comparatively

Fig. 2. Field work on Mt Kilimanjaro with a Russian corer (Photo: H. Behling) and a cored short core.

moderate climatic variability during the LGM. Therefore, Mt Kilimanjaro played a similar role as a glacial refugium for montane forest species as the Eastern Arc Mountains do. The downward shift of vegetation zones during the LGM seems to have caused changes in taxa composition within the vegetation zones but did not lead to elimination neither of vegetation belts, nor of major taxa dominating these belts today. Unlike major parts of western equatorial Africa, where the humid forest area was reduced by 84 %, the mountains of east equatorial Africa seem to have received sufficient precipitation to sustain most of their forest taxa, even throughout the LGM.

Very dry and cool conditions prevailed during the early last Glacial, probably interspersed with extreme drought events. During the pre-LGM more humid conditions allowed the ericaceous and forest vegetation to spread and caused an upwards shift of vegetation zones.

The pollen record from Maundi crater further showed, that during the last Glacial, especially the development of an *Erica* zone was strongly controlled by fire activity. Spread and decline of this vegetation zone oscillated depending on climate and fuel controlled fire dynamics. Hence, regular fires had a stabilizing effect on the vegetation composition. Despite the increased fire occurrence during the past century, fires were relatively rare during the Holocene, giving no indication for increased anthropogenic influence.

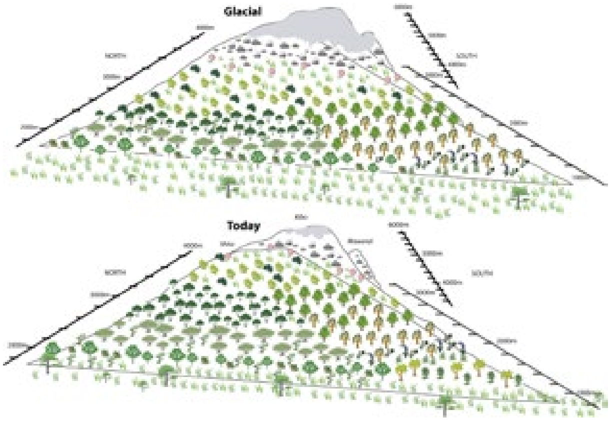


Fig. 3. Schematic overview of the shift and changes of vegetation zones on Mt Kilimanjaro. While during the Glacial vegetation zones were shifted downslope and most likely reduced in total area due to colder and probably drier climatic conditions, these vegetation zones moved upslope and showed an expansion during the warming of the Holocene.

Fig. 4. Maundi Crater located on the southwestern slope on Mt Kilimanjaro at 2780 m (Photo: L. Schüler).

Establishment of a modern pollen rain – vegetation relationship and pollen-based climate reconstructions on Mt Kilimanjaro

Since past shifts in the distribution of vegetation types are reconstructed from fossil pollen assemblages, the exact relationship between modern vegetation and modern pollen compositions is crucial for calibration of the fossil pollen records. Such calibration studies which quantitatively relate pollen with altitude or climatic parameters are still lacking in tropical Africa. One key objective of this research, therefore, was to establish exact pollen – vegetation and pollen – climate relationships, from which transfer functions can be developed for detailed reconstruction of past vegetation and climate states from fossil pollen records. The accomplished modern pollen-rain study provides insight into how present vegetation is reflected in the modern pollen rain along the elevational gradient of Mt Kilimanjaro. The results indicate that it is crucial to establish a modern pollen – rain – vegetation relationship for the calibration and interpretation of a fossil pollen record from a mountain site. At our study site it is possible to analyse the pollen-rain on plant family level to derive the forest zone of the surrounding vegetation and with this to assess the climatic conditions, which is important for the interpretation of palaeo-records. Even the separation of thin elevational belts such as lower and upper to mid montane forest zone is possible by modern pollen-rain. The occurrence of plant families along the altitudinal gradient is differently represented in the modern pollen depending on various reproduction factors.

The pollen and spore dispersal seem to be strongly influenced by the regional wind patterns. This needs to be considered when deriving past distribution ranges from pollen-records. Our results facilitate the confident use of fossil pollen data to reconstruct more precisely potential vegetation and its dynamics in East African montane forests, and to refine climate past reconstructions in this region for a more accurate comparison of data and modelling.

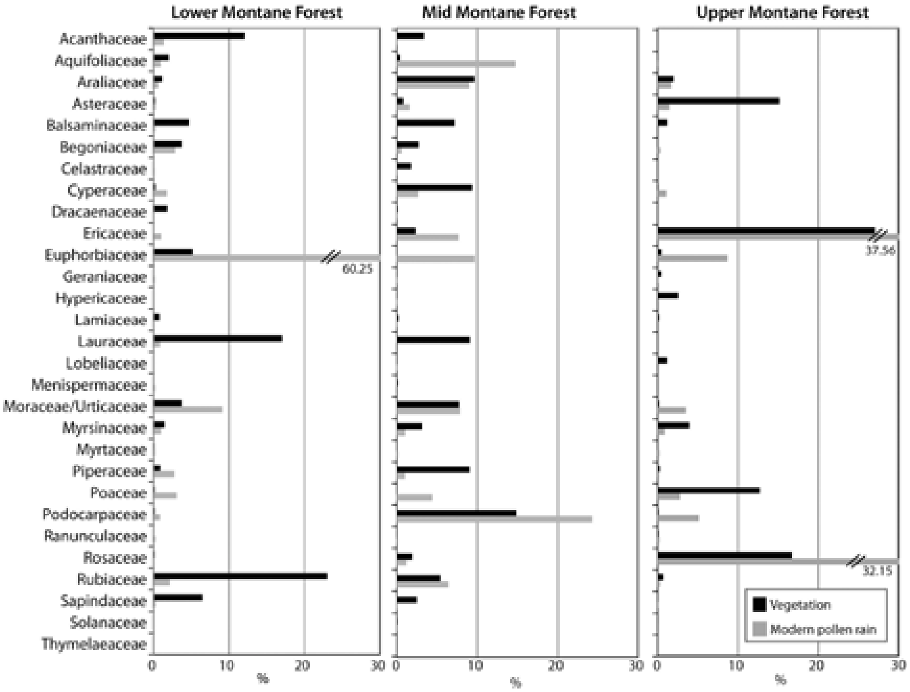


Fig. 5. Summary histogram comparing percentage data on family level of the modern pollen-rain and plant taxa in vegetation plots for the different montane forest zones.

Pollen-based temperature and precipitation inferences for the montane forest of Mt Kilimanjaro during the last Glacial and the Holocene

The development of mathematical transfer functions allows the 'translation' of fossil pollen data to specific climate data, by comparing the composition of modern pollen rain collected within the surrounding vegetation and local climate conditions. For the development of the pollen-climate transfer functions along an elevational gradient between 1900 and 3200 m at Mt Kilimanjaro, weighted-averaging partial least square regression models (WA-PLS) were used.

Our model suggests that during the late Glacial climate conditions were on average 1.6°C cooler and 12.5% drier than today. After the LGM our model suggests a trend towards warmer and wetter conditions. The MAP (mean annual precipitation) increase stabilizes after ~2000 years ago.

Although these results generally show the MAT (mean annual precipitation) and MAP trends also recorded in other climate archives in Central East Africa, our preliminary results will be improved by the application of a larger training data set covering a longer climate gradient along Mt Kilimanjaro.

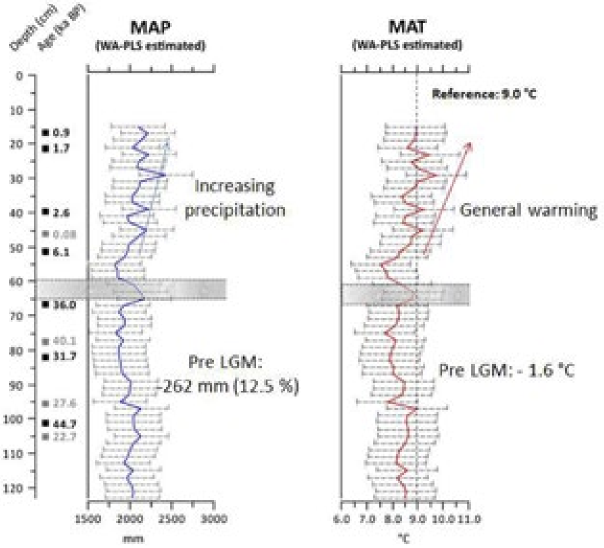


Fig. 7. Reconstruction of mean annual precipitation (MAP) and mean annual temperature (MAT) of the WW26 pollen data set using weighted-averaging-least square regressions (WA-PLS). As a reference, the present MAT (10.05 °C) and MAP (2230 mm) for the study site WW26 at an elevation of 2650 m are given (dashed, grey line).

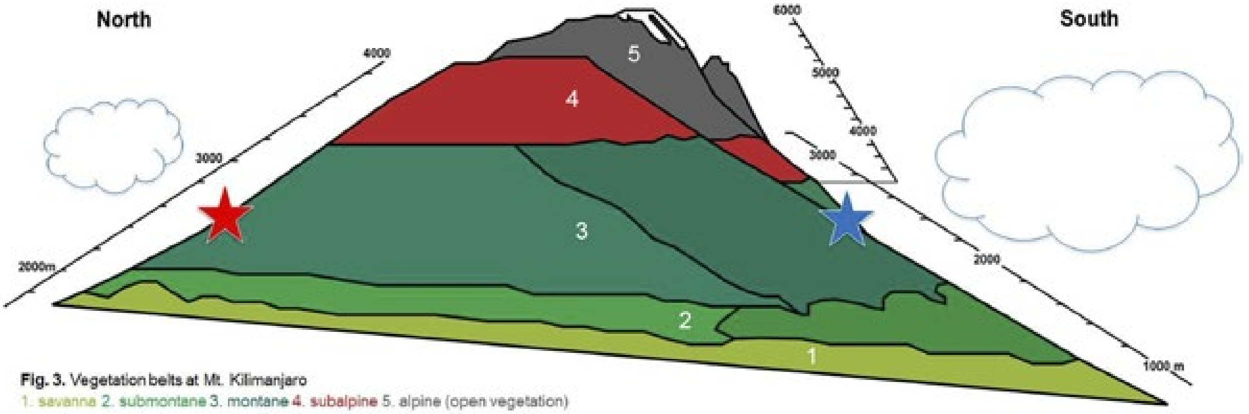


Fig. 6. Schematic overview on the different vegetation zones on the wetter southern and drier northern slopes on Mt Kilimanjaro. The Weru Weru study site (blue star) and the Bamboo study site (red star) on the northern slope are both at 2600 m elevation and today located within in montane forest.

Does drought make a difference?

by Vincent Montade, Lisa Schüler, Andreas Hemp and Hermann Behling

In addition to the previous pollen archives from the southern slope we also analyzed pollen data from the last 40,000 years from the northern slopes, which experience considerably less precipitation and show deviating vegetation zones and species composition. We focused on the pollen and phytolith (silica cells) analysis in different levels of the soil profile to evaluate the main tree and grass species composition changes in the past.

The middle-upper montane forest transition with small stands of bamboo did not always grow at the elevation of our study site (2600 m a.s.l.). Under cold and dry climate conditions during the LGM, the subalpine vegetation associated with some components of afro-alpine grassland extended further downward at the expense of the montane forest. Surprisingly, in contrast to Mt Kenya, we could show that an upward C4-grass expansion during that time was absent. Under warmer and more humid conditions during the following periods, the African Humid Period up to modern conditions, all the vegetation zones moved upward as indicated by the development of the upper montane forest specific tree taxa such as *Podocarpus*, Araliaceae, *Hagenia*, *Ilex* and *Olea*.

Hence, the vegetation dynamic reveals that an open subalpine vegetation associated with some components of alpine grassland dominated around the study site at 2600 m during the late Glacial. This contrasts with the southern slope where upper montane forest still dominated at the same elevation at the same time. This forest type only developed during the Deglaciation at 2600 m on the northern slope. Hence, drier and colder conditions during the late Glacial seem to have a stronger impact on the vegetation zonation on the northern slope.

By providing a better knowledge of past vegetation dynamics on Mt Kilimanjaro, of which latter is an "icon" of global warming because of its vanishing glaciers, such knowledge is also crucial to provide reliable benchmarks in tropical mountain environments to evaluate future vegetation changes.

Implications

Our investigations and reconstructions of former vegetation and climate dynamics unravel the ecosystem responses to climate change in the past and adds to the understanding of the state and functioning of the ecosystems of Mt Kilimanjaro. These pollen-based vegetation and climate reconstructions have shown that in the past plant taxa tended to sometimes respond individually, and sometimes in groups to environmental change.

Based on the tendency of many tropical species to move upslope under current global warming, species on Mt Kilimanjaro may be directly threatened by climate-induced range shifts in several ways. This might include the disappearance or decline of species in the lowlands and at lower elevations due to upslope movement of species, the extinction of high elevation species since there are no options for migration, and the inability of species to shift into a suitable geographic range either due to geographical barriers or insufficient dispersal capability.

Fig. 8. Pollen grain of *Podocarpus* sp. under the microscope (Photo: Vincent Montade).

On East African mountains such as Mt Kilimanjaro the montane and subalpine forests have a high potential of collecting precipitation and cloud water. Developed in-between lowland savannas and alpine vegetation, montane forests are of great importance for the watershed functioning because of their role in groundwater recharge. The large altitudinal range of such mountains enables plant communities to shift and adapt under climate changes to match their ecological needs. However, on Mt Kilimanjaro, as in many tropical regions, increase of human disturbances combined with reduction of precipitation during the last decades diminishes the altitudinal shift ability of montane forest challenging its resilience.

Unlike major parts of western equatorial Africa, where the humid forest area was reduced by 84% during the LGM, the mountains of east equatorial Africa seem to have received sufficient precipitation to sustain most of their forest taxa. The stabilizing effect of the moisture carrying Indian monsoon is probably the most important prerequisite enabling the East African mountain systems to have served as glacial refugium for montane forest taxa which makes the area one of the world's biodiversity hotspots today. But this also means that a change of precipitation will be the most influential factor for ecosystem changes and loss of biodiversity at Kilimanjaro.

Fig. 9. Short break during the fieldwork in the subalpine zone on the northern slope of Mt Kilimanjaro (Photo: Andreas Hemp).

Fig. 10. Example of soil profile sampled on the northern slope of Mt Kilimanjaro in December 2016 showing several layers characterized by different colours from the top to the bottom (Photo: Vincent Montade).

A milestone in pollen identification – the East African Pollen and Spore Atlas

by Lisa Schüler & Andreas Hemp

The accurate and consistent identification of fossil pollen is essential to allow robust inferences to be drawn with regard to past vegetation and climate change. In our atlas of pollen and spores and their parent taxa of Mt Kilimanjaro and tropical East Africa we contribute to this growing body of work by presenting images of 240 pollen types (in 202 genera and ~79 families) and 30 spore types (in 25 genera and ~17 families) from a wide range of different vegetation types originating from the Kilimanjaro area and tropical East Africa. Furthermore, we set a benchmark for the correct and consistent identification of pollen grains and spores from East African sediment records and modern pollen rain samples. We provide an overview on the range of most important pollen and spore types found in the last glacial and Holocene environmental archives in studies on and around Mt Kilimanjaro. The additional information on plant pollination and habitat makes this atlas a useful guide for palynological investigations, aiming at detailed and comprehensive reconstruction of past vegetation, environmental and climate change in tropical East Africa. Knowledge about the pollen and spore flora of the region is still limited, the list of pollen and spores is far from being exhaustive, and additional investigations are required. We will also be adding palynological descriptions of more pollen and spore types from tropical East Africa as our reference collection is not exploited by far and consistently growing. Further, all morphological descriptions of pollen grains will be made accessible and searchable in the online Goettingen and Spore Image Database (http://gdvh.uni-goettingen.de/).

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Atlas of pollen and spores and their parent taxa of Mt Kilimanjaro and tropical East Africa

Lisa Schüler [a,*], Andreas Hemp [b]

ARTICLE INFO

ABSTRACT

1. Introduction

Citation: Schüler, L., Hemp, A., 2016. Atlas of pollen and spores and their parent taxa of Mt Kilimanjaro and tropical East Africa. Quaternary International 425, 301–386.

Acknowledgements

We are grateful to the German Research Foundation (DFG) for providing the funding for these projects (BE2116/15–1, BE2116/15–2 and SCHU 2978/1–2).

Subproject 5

Plant functional traits translated into vegetation dynamics – Responses to environmental factors and effects on ecosystem functions of the Kilimanjaro region

Plant traits and their relationships with environmental conditions and ecosystem properties

by David Schellenberger Costa & Michael Kleyer

The use of plant traits, rather than taxonomic specification, as a way to predict changes in vegetation and ecosystem properties in response to environmental change has become increasingly important in recent decades. Traits are plant properties that indicate growth, maintenance, reproduction and dispersal functions. For example, specific leaf area describes leaf area, i.e. the area that intercepts light, in terms of biomass investment. Plant height indicates the capacity to shade other plants and seed size indicates dispersal, among others, as smaller seeds can be better transported by wind (Fig. 1).

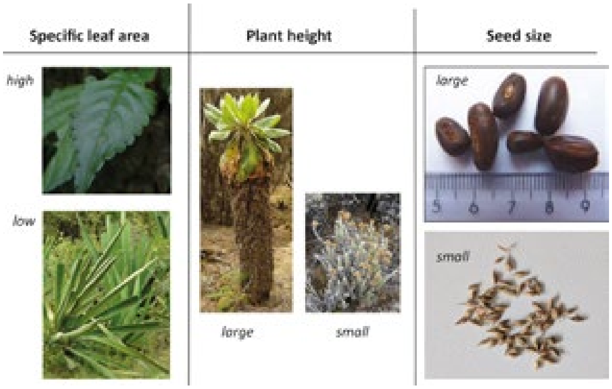


Fig. 1. Examples of plant traits.

Fig. 2. Variation in traits in four communities. Upper left: high variation in growth forms in a rain forest; upper right: intermediate variation in an *Erica* forest; lower left: low variation in subalpine herbaceous communities, characterized by strong daily variation in temperature; lower right: almost no variation in traits in a sugar cane plantation.

The analysis of trait responses to environmental conditions should assist in a better understanding of the species niches on the slopes of Mt Kilimanjaro. Traits can be used to aggregate the overwhelmingly large diversity of plants to groups of species that share similar trait expressions. Environmental management can strongly benefit from a functional approach that identifies key plant groups with specific environmental sensitivities or ecosystem effects. Changes in the abiotic environment can affect ecosystem properties and processes through shifts in the species composition of plant communities and concomitant changes in biological properties. Plants with appropriate trait expressions may either respond directly to the abiotic environment or through biotic interactions with other species. It has been proposed that traits affecting plant growth such as specific leaf area and canopy height are likely to be key determinants of primary and secondary productivity, matter decomposition and nutrient cycling. Studies comparing multiple traits of tropical plant communities have strongly increased in

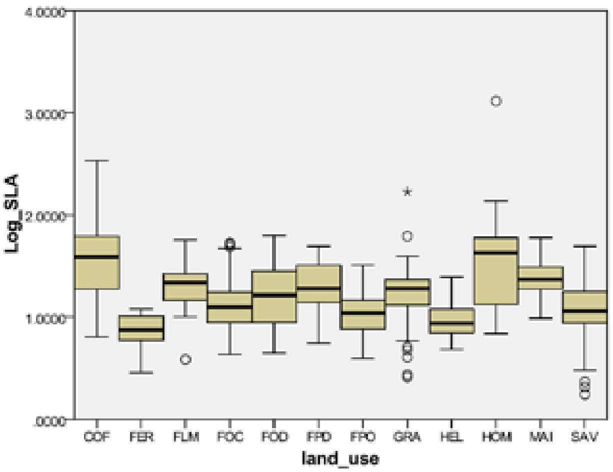


Fig. 3. Mean specific leaf area per vegetation and land- use types. Cof: Coffee; Fer: *Erica* forest; Flm: Lower Montane Forest; Foc: *Ocotea* Forest; Fod: Disturbed *Ocotea* Forest; Fpd: Disturbed *Podocarpus* Forest; Fpo: *Podocarpus* Forest; Gra: Grassland; Hel: *Helichrysum*; Hom: Homegarden; Mai: Maize; Sav: Savanna.

recent years, although not from tropical Africa. Our studies on Mt Kilimanjaro aimed at closing this knowledge gap.

One of our objectives was to understand how plant traits change along gradients of precipitation, temperature, soil nutrients, and disturbance on Mt Kilimanjaro. We assumed that the variation of the traits of all plants in a community should decrease towards the extreme and stressful end of an environmental gradient such as the driest or least fertile part of a gradient, due to a reduction in the number of viable plant life strategies (Fig. 2). On the other hand, traits indicating rapid growth and resource acquisition should increase with resource availability and disturbance intensity. Mean trait values per community were indeed very different, showing that trait respond to environmental conditions. For instance, specific leaf area was very low in the plant communities occurring at the highest elevations (Ffo, Fer, Hel; Fig. 2), indicating slow growth and conservation of resources in leaves in these stressful environments. Changes in trait expressions and changes in species composition in correspondence with changing environmental conditions indicate niche processes, i.e. the environment filters plants with trait expressions that are best adapted to the environment. However, there may be situations where species composition changes although the trait composition does not change. This may indicate random dispersal and colonization processes or subtle combinations of niche and dispersal processes. For instance, over an elevational gradient of about 1100 m with significant changes in precipitation and temperature, the trait composition of the rain forest types remained very similar (Foc, Fod, Fpo, Fpd, Flm, Fig. 4), whereas species composition varied considerably. Further upwards, around 3000 m a.s.l., where *Podocarpus* forests changes to *Erica* forests, a strong shift in trait filtering occurs, resulting in high taxonomic and trait variation across the plots belonging to these vegetation types. Above this elevation and up to the *Helichrysum* zone, where regular frosts occur each night, trait-independent species turn-

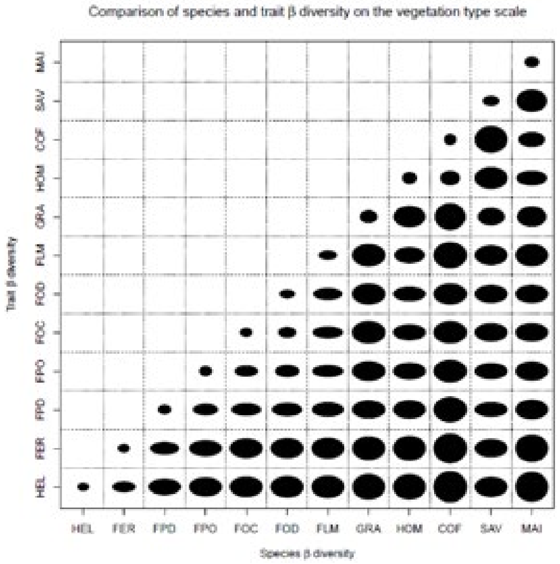


Fig. 4. Vegetation units are arranged according to their elevational distribution (from high to low elevations). Horizontal ellipse diameters represent species β diversity, vertical ellipse diameters show trait β diversity. For instance, the ellipse of Hel with Fer shows that there is higher difference in species than in trait values, whereas the ellipse of Hel with Cof shows that both species identities and traits are different between both vegetation types.

over occurred again, as different species shared similar traits indicating adaptations to a cold and dry climate. We have learnt from this study that the trait composition of plant communities often responds in steps to linear environmental changes. When temperature and precipitation change gradually along the mountain, the growth and life forms in plant communities appear unaffected. However, when a certain environmental threshold is passed, plant strategies are altered and reorganized to provide new survival opportunities.

Many animals feed on plants. Bees collect nectar from flowers. The plants themselves depend on abiotic conditions, such as soil, water and nutrients. People affect abiotic conditions by changing the management of the land. It would therefore be useful to model the changes in abiotic conditions due to changes in management, which in turn leads to changes in plants and their traits, which finally affect the next trophic levels, especially animals. One property of animals is their body size, which is assumed to depend on temperature or resource availability, among others. For animals depending on plants, resource availability may directly be related to plant traits. We determined the response of plant traits selected to reflect resource availability for animals to changes in precipitation, temperature and disturbance. We also assessed whether these abiotic factors or the plant traits were stronger predictors of the mean body size of bees (Fig. 5). We found that traits indicating plant tissue density and nutrient content strongly responded to variations in precipitation, temperature and disturbance. They had direct effects on the number of insect-pollinated plants and the total biomass of the plant communities.

However, the average bee body size could only be explained by temperature and total biomass, not by plant traits. Our results demonstrate a strong link between traits and the abiotic environment, but suggest that temperature is the most relevant predictor of mean bee body size. Average values of the traits of all species in a community appear unsuitable to capture the complexity of plant-animal interactions.

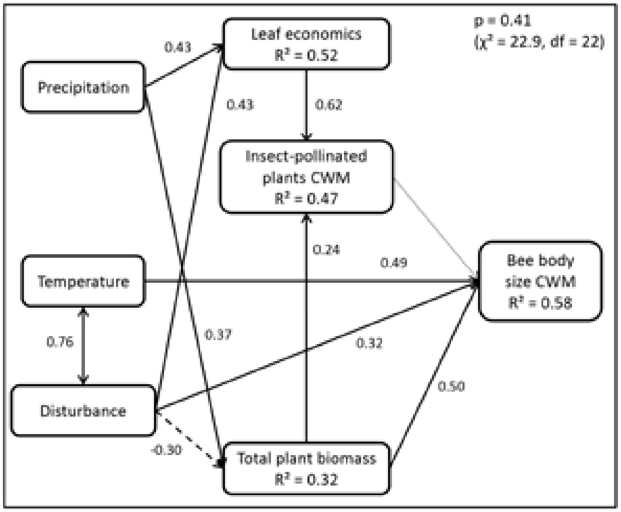


Fig. 5. Statistical model showing the relationship between the abiotic environment, disturbance, plant functional traits and mean bee body size. Standardized coefficients are given for positive (solid lines) and negative (dashed lines) relationships. Double-headed arrows denote correlations of abiotic factors. Dotted lines indicate hypothesized relationships that were not supported by the data, i.e. which turned out to be non-significant in the regression models.

Fig. 6. PhD student David Schellenberger Costa and Andreas Hemp during KiLi research plot installation.

Extraction of non-timber forest products on the slopes of Mt Kilimanjaro

by Hawa Mushi, Michael Kleyer & Pius Z. Yanda

Non-timber forest products (NTFPs) constitute significant benefits rural people obtain from natural forests on the slopes of Mt Kilimanjaro. NTFPs embody all biological matter of wild plants and animals other than timber extracted from forests and woodlands, e.g. fruits, nuts, vegetables, game, medicinal plants, resins, bark, fibers, palms, grasses as well as small wood products, amongst others. Many households in the area need resources available in the forested slopes, such as wood for cooking, heating and construction or forage for livestock. In 2001 the World Bank estimated that globally some 1.6 billion people depended on the extraction of NTFPs from protected forests (World Bank, 2004: Sustaining Forests: A Development Strategy. Washington). Other studies indicate that as much as 20–25% of rural people's income may be derived from environmental resources in developing countries. Little is known about the extraction of NTFPs on the slopes of Mt Kilimanjaro and their relationship with socio-economic factors such as gender, age, income, property size and distance to the forest. To further our understanding of the dimensions of NTFP extraction, to improve participatory forest management and to foster a sustainable flow of socially and economically valuable goods and services from forests, we conducted a study in six villages on the southern slopes of Mt Kilimanjaro. Based on available studies from other tropical countries, we assumed that NTFP extraction should increase with decreasing household income and property size and should also be gender- and age-biased. Specifically, we assumed that most of the NTFP extraction is done by younger women, except for medicinal plants which should mainly be collected by older persons. In addition, extraction should decrease with increasing distance from the villages to the next forest patches.

In the six villages, a total of 313 households were randomly selected and the heads of households interviewed. Both male and female household members were interviewed. Specifically, we asked about the frequency of visits to forests to collect firewood, fodder, fruits and vegetables, and medicinal plants. To explain these frequencies, the questionnaire included questions about gender, age, household size, household income, total land owned and cultivated. In each village, the interviewed households represented approx. 10% of the total household number. Two villages, Nronga and Foo, were located close to the Kilimanjaro National Park (1400 m a.s.l. or more), Shari and Nkuu-Ndoo in the homegarden belt (1000–1400 m a.s.l.) and Wari and Nshara at lower elevations (800 m a.s.l. and less). Since the establishment of the Kilimanjaro National Park in 1973, the local communities were allowed to collect forest products from a belt of land of about a half mile into the rain forest called the Half Mile strip. Thus, the villagers settling in the upper part mainly collect NTFPs in the Half Mile Strip. Those settling in the lowland and midland zone mainly used forested gorges and other small woodland patches. Most people in the villages rely on either firewood or charcoal for cooking. Whereas charcoal is a commercial product, firewood can be collected in forests, mostly be cutting down large branches or small trees. Fodder can be collected from the forest-understorey vegetation or from small forest gaps covered with herbaceous vegetation. However, fodder was also collected on grassland patches. These patches are found either uphill, i.e. close to the border of the Kilimanjaro National Park, on the slopes of the steep gorges intersecting the cultivated foothills of Mt Kilimanjaro, or on less fertile sites in the plains below Mt Kilimanjaro. Herbal medicines are collected to prevent and treat diseases. Vegetables and fruits collected in the forests are mainly wild passion fruits and mushrooms (Fig. 1). Between villages, we found strong differences in the average extraction frequency of forest resources (Table 1). For instance, people from Wari rarely went to the forest to collect firewood, whereas people in other villages went two times a week. People from Foo, Wari and Shari rarely used fodder from forests, whereas people from Nshara, Nkundoo and Nronga did this frequently. Across all villages, females collected more firewood and fodder than males, particularly if villages were close to the forests (Table 2).

Fig. 1. Collected firewood (left), fodder collection (center), *Aloe secundiflora*, a medicinal plant (right).

Table 1. Frequency of forest product extractions per study village and year

	Firewood	Fodder	Fruits and vegetables	Medicinal plants
Foo	87.82	1.64	2.27	3.67
Nshara	92.05	101.61	2.71	2.92
Nkuundoo	87.51	98.93	3.78	2.80
Nronga	99.48	101.74	1.43	2.72
Wari	0.94	2.52	2.30	4.16
Shari	93.36	0.41	1.48	21.27

Unmarried females went more often to forests to collect fodder than married ones. Except for firewood, people extracted more fodder, fruits and vegetables and medicinal plants when forests patches were close to the villages. Families with less income and with less land owned extracted more medicinal plants. Extraction of medicinal plants also increased with household size and decreasing household income. Males more frequently collected medicinal plants than females. Age or marital status did not influence the extraction of fruits and vegetables or medicinal plants. Other socio-economic parameters were not significant at the $p<0.05$ level. Our results suggest that households in all villages extracted forest products. This demonstrates that natural forests can provide important provisioning services for local communities. One respondent was quoted agreeing to this saying: “We collect almost all that is useful from the forest. This ranges from dry firewood, vegetables, fodder and also medicinal plants. These forests can be our own small forest gorges nearby or the Kilimanjaro National Park forest. We cannot imagine life without the forests considering that firewood is our main source of energy” (Respondent, Nronga village). However, extraction frequencies differed strongly between villages, particularly for firewood and fodder. There was relatively low intra-village variation regarding firewood and fodder extraction, suggesting that differences in access to infrastructure and alternative sites to produce fodder were the main determinants of NTFP extraction. A major indicator of access to infrastructure is the proximity of the village to the main roads.

Table 2. Relationships between the extraction frequency of forest resources and socio-economic predictors, based on a negative binomial regression analysis, separately for each product. Coef: predictor coefficient; P: probability. Significant predictors printed in bold ($p < 0.05$).

	Firewood		**Fodder**		**Medicinal plants**		**Fruits & vegetables**	
Predictor	Coef	P	Coef	P	Coef	P	Coef	P
Gender= Females	**0.38**	**0.00**	**0.80**	**0.00**	**-0.52**	**0.00**	0.10	0.50
Marital Status= Married	-0.11	0.42	**-0.25**	**0.07**	0.10	0.55	0.02	0.92
Age	-0.003	0.47	0.001	0.89	-0.01	0.12	0.01	0.18
Household size	0.01	0.71	-0.03	0.39	**0.11**	**0.03**	**-0.08**	**0.03**
Household income	-9.412E-8	0.50	5.579E-9	0.96	**-4.64E-7**	**0.00**	-4.311E-8	0.80
Land owned	-0.07	0.51	-0.14	0.19	**-0.62**	**0.00**	0.24	0.06
Land cultivated	0.05	0.69	0.09	0.48	**0.69**	**0.00**	-0.21	0.14
Distance to forest	-0.08	0.42	**-0.57**	**0.00**	**-0.32**	**0.01**	**-0.31**	**0.00**
R^2								

Roads often serve as market places where commodities such as charcoal are sold as an alternative to firewood. Wari is located close to the main road which may provide an additional explanation why households in Wari collected very few firewood, apart from the distance to the nearest forest. In contrast to our expectations, neither firewood nor fodder extraction depended on household wealth or size, indicating a uniform dependency on firewood and fodder from forests within villages. Other socio-economic factors varying both at the inter- and intra-village level provided significant additional explanation, but only on selected forest resources, such as medicinal plants or fruits and vegetables. The latter were collected much less frequently than firewood or fodder, probably due to their seasonal availability.

Normally, fodder grown in homegardens is not enough to feed all cows, so households have to extract additional fodder from the forest. This was more often done by unmarried females than by males or married females. In an interview a female respondent explained:

"We women are more concerned with almost all household activities, from cooking, collecting firewood, feeding cows, tending to chickens, cleaning. Sometimes we are also involved in income generating activities like when we cultivate a little more and sell out the rest of the harvest but all the income is for the man. He plans how to spend it for all of us. It has always been like that, from our ancestor's time up to now" (Respondent, Nkuu-ndoo village).

Our study demonstrates that natural forests can provide important provisioning services for local communities. On the other hand, extraction of non-timber forest resources can strongly affect the structure and biodiversity of natural forests. Firewood collection belongs to the most detrimental uses of natural forests as it weakens adult trees, destroys young trees and diminishes nutrient fluxes by biomass removal. Conservation methods should be inbuilt in forest resources utilization to ensure sustainability. Sustainable forest management should include capacity building, awareness rising and participatory involvement of the local communities.

Fig. 2. PhD student of SP 5, Hawa Mushi.

Modelling biosphere-pedosphere interaction at Mt Kilimanjaro

by Friedrich Bohn, Hans Henniger, Andreas Huth & Ralf Kiese

Climate and land-use changes challenge ecosystem stability and services at the forests of Mt Kilimanjaro. A detailed understanding and characterization of biotic and abiotic as well as above- and below ground processes on ecosystem C, N, and water cycling are needed.

Data obtained by field and laboratory measurements on climate (Syn1), vegetation (Syn3), physical and biogeochemical soil characteristics and dynamics (Syn2, P1) prepare the ground for coupling the biogeochemical model LandscapeDNDC and the dynamic vegetation model FORMIND. FORMIND is a forest gap model, which simulates establishment, competition, growth, and mortality of each single tree within a forest (Fig. 2). Model parameters were calibrated using forest inventory data from different forest research sites. The model is already validated for Kilimanjaro by comparing simulated leaf area index with independent field measurements. Carbon balances, biomass stocks or structural forest characteristics of a montane tropical forest can be analyzed.

The estimated aboveground biomass (385 t ha-1) and photosynthesis rate of 24 t C ha^{-1} yr^{-1} are comparable to values in the Amazon and other tropical forests in Africa. Litter fall and dead trees are the main input of carbon and nitrogen into the soil initiating decomposition processes. These processes are simulated with the soil model LandscapeDNDC, which takes also into account the available soil water, soil temperature, redox potential and pH. Depending on the soil conditions, the organic substrates are decomposed to various greenhouse gases (like methane, carbondioxid, different nitrogen oxides) or to plant available nitrogen.

The model can be easily calibrated and validated with the available field measurements to the conditions of Mt Kilimanjaro. Based on the simulated available soil water and plant available nitrogen the growth of trees in FORMIND can be enhanced or inhibited (Fig 3 & 4).

These coupled models will be used to evaluate different coupling approaches (Fig. 5). In the big leaf approach, vegetation is very simple represented as a green layer with a certain biomass. Species and trees are only represented in the approach "one port" and "patch wise ports", whereby in the first case the whole forest is coupled to one single soil representation. In "patch wise ports" coupling, small forest patches are linked with local soil representations, which would result in a heterogeneous distribution of soil characteristics. The coupled model (FORMIND and LandscapeDNDC) will allow the evaluation of impacts of climate and land-use intensity on C, N and water cycles and budgets of Kilimanjaro ecosystems, which finally allow generating functional relationships between

Fig. 1. Lower mountain forest (plot Flm1).

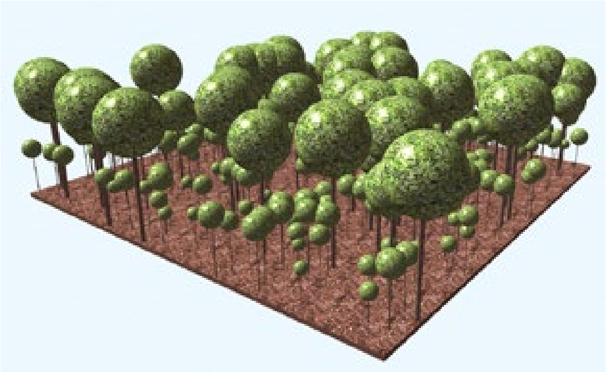


Fig. 2. Exemplary visualization of a simulated forest stand on Mt Kilimanjaro (1 ha) showing all trees with a stem diameter > 10.

land-use, water and biogeochemical cycles under current climatic conditions. Within scenario studies of climate and land-use intensity change, we will further reveal, how these relationships might change in the future. We hypothesize that climate change as well as land-use intensification has negative impacts on C, N and water cycles of Kilimanjaro ecosystems, which will reduce biodiversity, ecosystem stability and services.

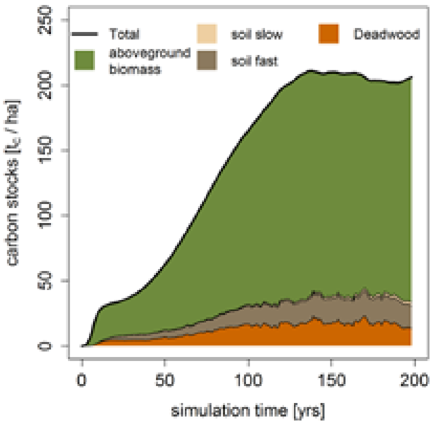


Fig. 3. Simulation of different carbon pools of a mountain forest.

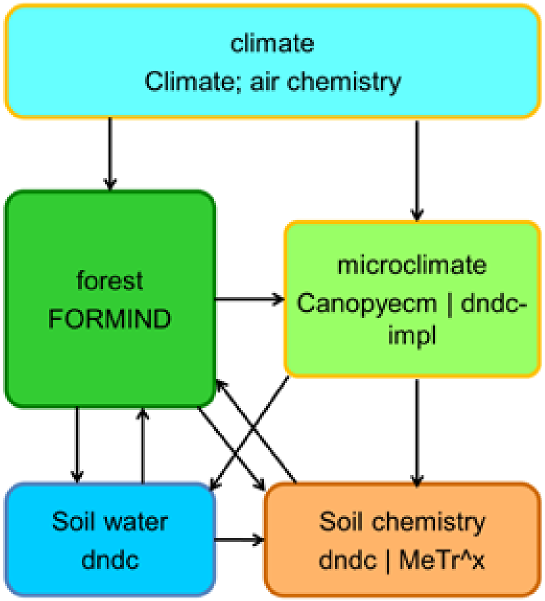


Fig. 4. Coupling concept for FORMIND and LandscapeDNDC. FORMIND simulate forest processes and the micro climate (light). Landscape DNDC simulate water balance and decomposition of organic substrate.

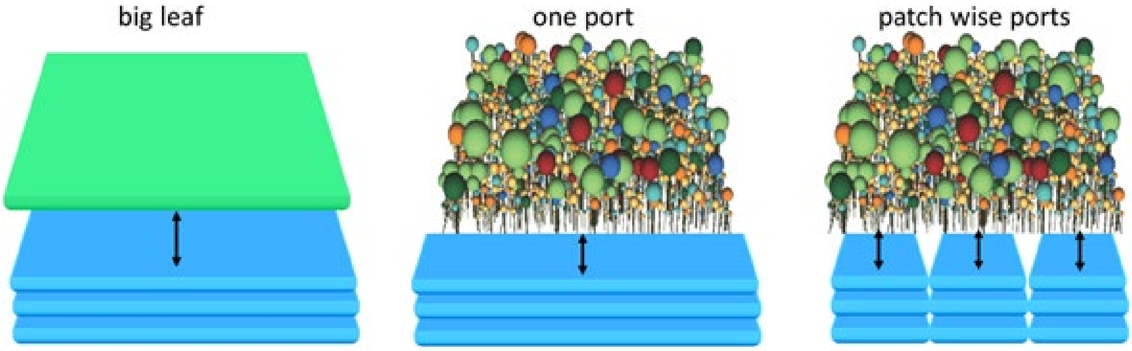


Fig. 5. Different coupling approaches between aboveground (FORMIND) and belowground processes (LandscapeDNDC).

Subproject 6

Biodiversity and ecosystem functioning: birds and bats as seed dispersers and arthropod predators

Frugivorous and insectivorous bats on the slopes of Mt Kilimanjaro

by Anna Vogeler, Maria Helbig Bonitz, Elisabeth Kalko & Marco Tschapka

Mountain slopes cover broad climatic and vegetational gradients and may harbour an immense biodiversity. These gradients allowed us to investigate the reactions of organisms to climatic and habitat changes over a relatively small spatial scale on the slopes of Mt Kilimanjaro. Bats, being highly mobile and the second most species-rich order of mammals, cover a variety of ecosystem functions such as seed dispersal, pollination and insect predation. Therefore, they are very important, e.g., for agriculture and since they are also very sensitive for environmental changes, they are very suitable model organisms. Negative responses of bats to anthropogenic disturbances are likely to have considerable impact on entire ecosystems, including agricultural systems. A loss of bats might result in smaller crop size, the need for more expensive pesticides and lower forest regeneration success.

In our subproject we investigated the relationship between habitat disturbance and elevational distribution patterns of bats, using both acoustic monitoring of bat vocalizations and mistnetting techniques.

Based on echolocation calls we recorded 20 aerial insectivorous bat species in twelve different habitat types along the slopes of Mt Kilimanjaro, representing six elevational zones that comprise both natural and disturbed habitats. Most insectivorous bats were found between 1100 and 1750 m a.s.l. in natural habitats. Whereas habitat use and occurrence of bats were more affected by elevational changes, bat species composition changed significantly along both elevational and disturbance gradients. Some bat species seemed to be particularly associated with forested areas. Particularly these bat species are likely to react sensitive to further loss of forest cover in the region. Using mistnets we additionally registered six fruit bat species, representing important seed dispersers in five different habitat types (Maize, Savanna, Homegarden, Coffee Plantation, Lower Montane Forest) along the slopes of Mt Kilimanjaro. We found differences in fruit bat community composition among habitat types, indicating that the species responded differently to human land-use. The degree of specialization on fruit resources decreased with increasing mean annual temperature and land-use intensity for bats, suggesting a high tolerance against extinction. We further found that bats with distinct morphologies, such as jaw width or skull length, foraged on certain sets of plant species, which makes them specialists for these plants and promotes their endurance. The high degree of mobility of the fruit bats in combination with seed retention times in the digestive tract of more than

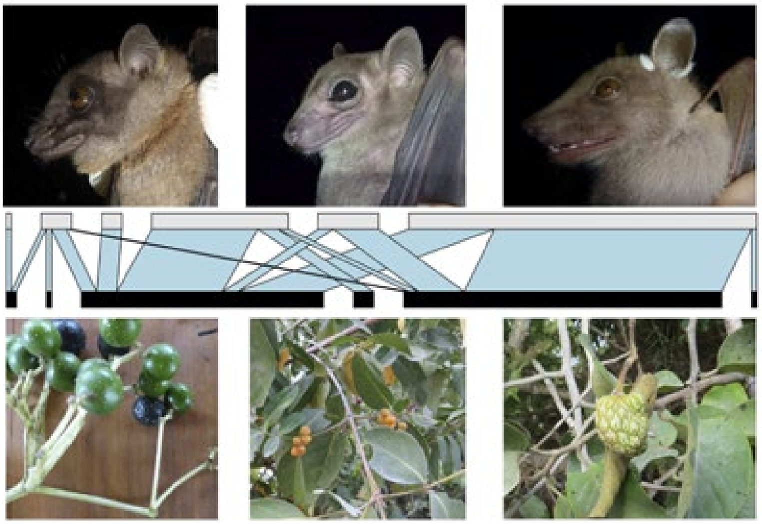


Fig. 1. Interaction network of frugivorous bats and the plant families they are feeding on. Box width corresponds to the relative fraction of interactions a species contributes to the network. Width of interaction lines is proportional to the number of observed interactions.

12 hours suggests a high potential for long-distance seed dispersal and the potential to link different habitat types. Therefore, changes in community composition caused by habitat degradation may have negative consequences on overall seed dispersal and forest regeneration functions also in adjacent habitats.
In conclusion, our study provided important insights into fruit bat diet and habitat use of insectivorous bats, and more generally stresses the importance of bats as seed dispersers and insect predators in the Mt Kilimanjaro ecosystem. Plants need bats for pollination, seed dispersal and protection against herbivorous insects and therefore for reproduction and long-term survival.

In **Figure 1** we see a seed-dispersal network of seven frugivorous bat species and their food plant families. Bats are represented by the boxes on the top of the figure and plant families are found as nodes at the bottom of the figure. Each box represents one bat species or one plant family. The width of the lines linking the nodes represents the number of bat-plant interactions, meaning the successful consumption of fruits within the plant family by a bat individual. Seeds were found in the fecal samples of the single bat individuals. The nodes represent the relative fraction of interactions a species contributes to the network.

Table 1. Alphabetical list of captured frugivorous bats (family Pteropodidae) and insectivorous bats with elevational distribution (m a.s.l.) on Mt Kilimanjaro.

Species	**Elevation**
Frugivorous bats	
Eidolon helvum	900–1900 m
Epomophorus minimus	800–1000 m
Epomophorus wahlbergi	1300–1700 m
Lissonycteris angolensis	1000–1800 m
Rousettus aegyptiacus	1000–1400 m
Rousettus lanosus	1000–2000 m
Insectivorous bats	
Cardioderma cor	800–1000 m
Chaerephon cf. pumilus	1200–1300 m
Hipposideros caffer	1000–1100 m
Pipistrellus sp.	1700 m
Miniopterus natalensis	1600–2000 m
Nycteris thebaica	1000–1400 m
Pipistrellus cf. *grandidiesi*	1100–1400 m
Neoromicia nana	1100–1600 m
Rhinolophus cf. *clivosus*	1600–2000 m
Rhinolophus sp.	1400–2200 m
Scotophilus dinganii	900–1400 m
Taphozous perforatus	800–1000 m

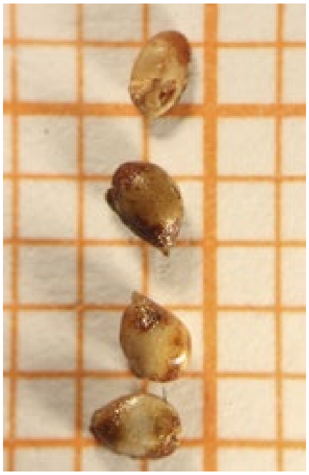


Fig. 2. Seeds extracted from faeces of bats. These investigations showed which plants are distributed by frugivorus bats.

Fig. 3. Measuring wing length of a "Flying Fox" (frugivorus bat). The student wears a face mask to prevent inhaling dangerous germs which bats sometimes transmit. The towel prevents harmful bites.

Photo series of bats of Kilimanjaro

Photos: Maria Helbig-Bonitz & Anna Vogeler
Text information by C. Hemp (source mostly IUCN Red List at: www.iucnredlist.org)

Frugivorous Bats

Fig. 1. *Eidolon helvum*, the **African Straw-coloured Fruit Bat**. This bat is broadly distributed across the lowland rainforest and savanna zones of Africa.

Fig. 2 & 3. *Epomophorus wahlbergi*, **Wahlberg's Epauletted Fruit Bat**. Typically recorded from woodland savannas. Roosting sites are often under the canopy of trees, with animals sometimes present in considerable numbers. The species is adaptable to human habitat modification. On Mt Kilimanjaro this species is common especially in homegardens. Individuals were also captured on the plots of the lower montane forest FLM 1 & 3, Savanna, Maize fields and Coffee plantations.

Fig. 4. The PhD student, Anna Vogeler, checks whether the wings of the bat are unharmed after it was net captured, immediately releasing the bat again after its has been measured and weighed.

Fig. 5. Maria Helbig-Bonitz, PhD student working on bats of KiLi Project phase 1.

Fig. 2. *Epomophorus minimus*, the **East African Epauletted Fruit Bat**. It is a low altitude savanna species restricted to eastern Africa.

Fig. 6. *Rousettus aegyptiacus*, the **Egyptian Fruit Bat**. Patchily distributed across sub-Saharan Africa and North Africa; also ranges outside of Africa through south-west Asia to Iran and Pakistan; also on Cyprus.

Fig. 5. *Lissonycteris angolensis*, the **Angolan Fruit Bat** or **Angolan Rousette**. It is found from Central to East Africa. Its natural habitats are subtropical or tropical moist lowland forests, moist savanna, and rocky areas.

Fig. 7. *Rousettus lanosus*, the **Long-haired Rousette**. This species is distributed in East Africa and marginally in Central Africa. It ranges from Ethiopia and southern Sudan in the north, into Kenya, Uganda, eastern Democratic Republic of the Congo and Rwanda, to Tanzania and northern Malawi. The photo shows an individual caught on plot Hom5.

Insectivorous bats

Fig. 8. *Cardioderma cor*, the **African False Vampire Bat** or **Heart-nosed Bat**. This East African species is distributed from north-east Sudan (near the Red Sea) south to central Tanzania. The distribution extends from the border area of Uganda and Sudan in the west, to east Somalia (near the tip of the Horn of Africa) in the east. Highest altitudinal record is 940 m.

Fig. 10. *Hipposideros caffer*, a wide-spread bat species with several common names: **Sundevall's Roundleaf Bat**, **Cape Leaf-nosed Bat**, **Common African Leaf-nosed Bat**, **Lesser Leaf-nosed Bat** or **Sundevall's Leaf-nosed Bat**. This species occurs from the south-western Arabian Peninsula (including Yemen) and across most of sub-Saharan Africa (except for central forested regions) (Photo plot Sav4).

Fig. 9. *Chaerephon* cf. *pumilus*, the **Little Free-tailed Bat**, a wide-spread species. It is found from Senegal in the west of its range, eastwards to Yemen and southwestern Saudi Arabia, and as far south as South Africa (Photo plot Hom4).

Fig. 11. *Miniopterus natalensis*, the **Natal Clinging Bat** or **Natal Long-fingered Bat**. This widely distributed species has largely been recorded from southern and East Africa, with some records from Central African and from the Arabian Peninsula. It has been recorded from semi-desert, dry and moist savanna, and mediterranean-type shrubby vegetation. It is generally a cave roosting species also found in disused mines.

Fig. 12. *Nycteris thebaica*, the **Cape Long-eared Bat**. Broadly distributed across savanna and riparian zones. It is mostly found in sub-Saharan Africa; it can also be found in Morocco, Libya, Egypt (primarily down the Nile River valley, but also into Sinai) and the Middle East (Israel, Palestine and Jordan). Elevation ranges from sea level to 2000 m. A savanna species with wide habitat tolerance. Occurs in moist and dry savanna, also ranging into desert, arid rocky areas, and riparian strips. Essentially a cave-roosting species but also roosts during the day in mine adits, aardvark holes, rock crevices, culverts under roads, roofs and hollow trees, typically in open savanna woodland.

Fig. 14. *Lavia frons*, the **Yellow-winged Bat** is widespread south of the Sahara. It is found in riparian habitats, in low lying *Acacia* woodland, thorn scrubland and savanna.

Fig. 13. *Pipistrellus* or *Neoromicia* cf. *grandidieri*, probably the **Dobson's Pipistrelle**. This inadequately known species appears to have been recorded from Angola, Burundi, Cameroon, Malawi, Mozambique, Uganda and Somalia. This species was not yet recorded from Tanzania. Bats allocated to this species have been recorded from both dry and moist savanna, lowland and montane tropical moist forest, and tropical dry forest.

Fig. 15. *Neoromicia nana*, the **Banana Pipistrelle Bat**, **Banana Bat** or the **Banana Pipistrelle**. This bat is widely distributed throughout most of sub-Saharan Africa and has been recorded from a wide variety of habitats. The rolled up, terminal leaves of bananas are frequently used as roosting sites, although the species has also been recorded in roofs and in the thatch of rural huts. Animals usually roost singly or as small colonies of two to six individuals.

Figs. 16 & 17. *Rhinolophus* cf. *clivosus*, probably **Geoffroy's Horseshoe Bat** (forest plot Flm5). Further taxonomic research is needed for *Rhinolophus clivosus* as this may represent a complex of several species. This species is widespread in North, East and southern Africa, and also in parts of southwest Asia, including western and southeastern areas of the Arabian Peninsula. Recorded from a wide variety of habitats, ranging from savanna woodland, Mediterranean-type shrubland, dry (and possibly moist) savanna, open grasslands and semi-desert to even more arid environments.

Fig. 18. *Scotophilus dinganii*, the **Yellow House Bat** or **African Yellow Bat**. This species is an opportunistic crevice or hollow dweller and usually prefers roofs with a ceiling in suburban areas, hiding between the wooden rafters and brickwork inside the roof. It is widely distributed in sub-Saharan Africa and has been recorded from both dry and moist savanna habitats.

Fig. 18. *Taphozous perforatus*, the **Egyptian Tomb Bat** occurs widely throughout northern and sub-Saharan Africa, the Arabian Peninsula, and Asia, east to the Indian Subcontinent (Photo Sav4).

Diversity of birds on Mt Kilimanjaro and their importance for ecosystem processes and functions

by Katrin Böhning-Gaese, Matthias Schleuning, Kim Howell, Stefan Ferger, Hamadi Dulle & Maximilian Vollstädt

Birds are the most species-rich group of terrestrial vertebrates and populate every major inhabitable environment on the planet. Birds are therefore pivotal elements of ecosystems and contribute to vital ecosystem processes through their interactions with other organisms. For instance, they contribute greatly to pollination, seed dispersal and pest control of insects. Consequently, birds are crucially important for the functioning of terrestrial ecosystems. Because birds are so vitally important, it is essential to understand how their diversity is distributed along large environmental gradients, such as the elevational gradient of Mt Kilimanjaro. Different environmental factors are being discussed as potential drivers of bird diversity. While some studies underline the importance of climate, other studies argue that resources, such as fruits, regulate bird diversity. In fact, resources have been shown to not only influence the species richness of birds, but also the interactions between birds and other species at the community level. Within the framework of our project, we addressed the following main questions: what drives the diversity of birds on Mt Kilimanjaro? How does global change, i.e. climate change and land-use, impact bird diversity? How do interactions between birds and plants change in response to environmental drivers? How do birds influence important ecosystem functions? First, we used point counts and mist netting to asses diversity of birds on our study sites distributed along the entire elevational gradient of the mountain. We additionally used time-series data to evaluate how bird communities have changed over the course of the last 20 years. We also recorded interactions between birds and plants to examine their interaction networks (Fig. 1) and related them to environmental factors, such as resource availability. Finally, we presented artificial clay fruits in all major habitat types and covered coffee plants with large nets to exclude birds and bats for testing the role of birds in important ecosystem functions such as seed dispersal and pest control. Answering these questions may help us to better understand how birds respond to environmental change and, thus, how we can conserve birds and their pivotal ecosystem functions in the future.

Fig. 1. Maximilian Vollstädt, KiLi PhD student of phase 2 training his team at Lake Chala.

Fig. 2. Graphical representation of a seed-dispersal network from Mt Kilimanjaro, comprising 86 bird species (top) and 71 plant species (bottom). Each black bar represents one species and each red line represents an interaction between a bird and a plant species. The size of the bars and lines indicates how abundant a species is and how frequently an interaction takes place.

Fig. 3. Stefan Ferger, PhD student of phase 1 with net captured **White-eye** (*Zosterops*). The birds are caught with a Japan net, measured, weighed and a ring is fixed to one of their feet. This ring will identify the bird once recaptured at any place of Africa. After this procedure the birds were immediately set free again.

Our results indicate that resources were the most important factor determining bird diversity along the elevational gradient of Mt Kilimanjaro, while climate influenced bird diversity mostly indirectly, through its effect on plant and invertebrate resources. Furthermore, the time-series approach indicated that the temperature increase over the last twenty years resulted in an average increase of bird abundance at high elevations. However, population increases differed among bird groups and were evident in forest generalists and omnivores, but not in forest specialists and insectivores. Additionally, we found that climate and land-use interacted in their effects on bird diversity. Specifically, high temperatures and high land-use intensity resulted in a higher change in bird communities than expected from their single effects, suggesting that climate change could exacerbate impacts of land-use on biodiversity. We also found that fruit resources were the most important driver of interaction networks between plants and birds. Both fruit availability and fruit diversity shaped the structure of interactions between birds and plants on Mt Kilimanjaro, while climatic effects were only of minor importance. Finally, we provide evidence for the relevance of birds for ecosystem functioning. The diversity of fruit-eating bird species determined how many fruits were eaten and potentially dispersed in the different habitat types. The exclusion of birds and bats from coffee plants led to a reduction in fruit set of ca. 9%. Hence, birds and bats are important pest control agents that significantly increase coffee yield. With our work we revealed important insights into the mechanisms shaping bird diversity on Mt Kilimanjaro, as well as the structure of their interaction networks with plants and their contribution to pivotal ecosystem functions. We were able to demonstrate that resources are the most important driver of the diversity of consumer species like birds, which has previously been underestimated, and shows that there is a high potential for cascading effects from plants to birds. We also confirmed the importance of direct climatic effects on bird diversity and found that not all bird groups respond to climate and land-use change in the same way. Our findings stress that the effects of different environmental drivers, such as climate and land-use, must be considered simultaneously, as the interactive effects of these drivers on bird diversity can be much greater than their individual effects. Ignoring that different drivers of global change act in concert, could underestimate the consequences of global change for biodiversity and ecosystem functioning.

Fig. 4. The research project of the KiLi PhD students Hamadi Dulle and Stefan Ferger were documented by a film team of ARTE.

List of all birds recorded on our study plots, distributed over the entire elevational gradient of Mt Kilimanjaro

Ibises and Spoonbills (Threskiornithidae)

Hadada Ibis

Pheasants, Partridges, Turkeys and Grouse (Phasianidae)

Scaly Francolin
Hildebrandt´s Francolin
Crested Francolin

Hawks and Eagles (Accipitridae)

Mountain Buzzard
Long-crested Eagle
Augur Buzzard
Gabar Goshawk

Parrots (Psittacidae)

African Orange-bellied Parrot
Red-fronted Parrot

Fig. 5. The **Augur Buzzard** (*Buteo augur*), is a large bird of prey, typically found on East African mountains such as Mt Kilimanjaro. The species is most common between 2000 and 5000 m a.s.l. **Augur Buzzards** can often be observed in pairs, and they are easy to spot, since they often make noisy aerial displays. The **Augur Buzzard** is an important species in ecosystems, as they regulate populations of small ground mammals by preying on them. The species also occasionally hunts on snakes, lizards and small ground birds and will even take carrion (Photo: C. Hemp).

Fig. 6. The **African Green Pigeon** (*Treron calvus*) is a large bird species, inhabiting riparian forest, woodland and savanna from sea level to 2000 m a.s.l. **African Green Pigeons** usually forage in small to medium-sized groups. Their diet consists almost exclusively of fruit, especially figs, which makes the species a particularly important seed disperser (Photo: C. Hemp).

Pigeons and Doves (Columbidae)

Red-eyed Dove
Ring-necked Dove
Olive Pigeon
African Green Pigeon
Blue-spotted Wood Dove
Tambourine Dove
Dusky Turtle Dove
Lemon Dove
Eastern Bronze-naped Pigeon
Laughing Dove
Speckled Pigeon
Emerald-spotted Wood Dove
African Mourning Dove

Turacos (Musophagidae)

Hartlaub´s Turaco
White-bellied Go-away-bird

Cuckoos (Cuculidae)

African Emerald Cuckoo
Klaas´s Cuckoo
White-browed Coucal

Typical Owls (Strigidae)

African Wood Owl
Spotted Eagle Owl
Verraux's Eagle Owl

Fig. 7. The **Von der Decken's Hornbill** (*Tockus deckeni*), is a large bird commonly found in thorn scrubs and similar environments. The species forages alone or in pairs, but can also form flocks outside of its breeding season. As most hornbills (Bucerotidae), the **Von der Decken's Hornbill** feeds on a large variety of resources and is considered omnivorous. Due to the large body size and large beak, the species is able to feed on large fruits, which makes the **Von der Decken's Hornbill** important seed dispersers of many plant species. Additionally the species commonly flies over large distances and can thus carry seeds to different environments, thereby connecting plant populations of different ecosystems (Photo: M. Vollstädt).

Swifts (Apodidae)
Alpine Swift
Scarce Swift

Mousebirds (Coliidae)
Speckled Mousebird

Trogons (Trogonidae)
Bar-tailed Trogon

Kingfishers (Alcedinidae)
African Pygmy Kingfisher
Striped Kingfisher
Brown-hooded Kingfisher

Bee-eaters (Meropidae)
Cinnamon-chested Bee-eater
Little Bee-eater

Rollers (Coracidae)
Lilac-breasted Roller

Hornbills (Bucerotidae)
African Grey Hornbill
Von der Decken´s Hornbill
Red-billed Hornbill
Silvery-cheeked Hornbill
Crowned Hornbill

African Barbets (Lybiidae)
Moustached Green Tinkerbird
Red-fronted Tinkerbird
Spot-flanked Barbet
Brown-breasted Barbet
White-eared Barbet

Woodpeckers (Picidae)
Cardinal Woodpecker
Golden-tailed Woodpecker
Olive Woodpecker
Nubian Woodpecker

Honeyguides and Honeybirds (Indicatoridae)
Eastern Honeybird
Greater Honeyguide

Fig. 8. The **Silvery-cheeked Hornbill** (*Bycianistes brevis*) is a very large and charismatic hornbill (Bucerotidae) species. **Silvery-cheeked Hornbills** forage in pairs and medium to large groups, flying very large distances to reach resources. With their noisy displays, they are easily detected and cannot be overseen. The species is omnivorous, but has a very large proportion of fruit in its diet. Due to the very large bill size, the species is capable of taking the largest fruits and is therefore an extremely important seed disperser for large-fruited plants (Photo: C. Hemp).

Fig. 9. The **Black-throated Barbet** (*Tricholaema melanocephala*) is a medium-sized bird species, commonly found in semi-arid bush and thorn-scrub from sea level to about 1500 m a.s.l. The species feeds on insects and forages alone or in small family groups. As other **African Barbet** species (Lybiidae), **Black-throated Barbets** also feed on fruits and play important roles in their ecosystems as insect predators and seed dispersers (Photo: M. Vollstädt).

Fig. 10. The **Spot-flanked Barbet** (*Tricholaema lacrymosa*), is another species of **African Barbets** (Lybiidae). It is slightly smaller than the **Black-throated Barbet** (*T. melanocephala*, Fig. 9), but is otherwise very similar in distribution and behavior. **Spot-flanked Barbets** have a larger proportion of fruit in their diet and are therefore important seed dispersers for many small-fruited plant species of savanna and bushlands at lower elevations (Photo: M. Vollstädt).

Pipits and Wagtails (Motacillidae)
African Pied Wagtail
Tree Pipit
Mountain Wagtail
Long-billed Pipit
Grassland Pipit

Larks (Alaudidae)
Flappet Lark

Swallows (Hirundinidae)
Black Saw-wing
Barn Swallow
Common House Martin
Red-rumped Swallow
Rock Martin
Lesser Striped Swallow

Bulbuls (Pycnonotidae)
Common Bulbul
Zanzibar Sombre Greenbul
Mountain Greenbul
Stripe-cheeked Greenbul
Northern Brownbul
Cabanis Greenbul

Starlings (Sturnidae)
Superb Starling
Wattled Starling
Kenrick´s Starling
Violet-backed Starling
Red-winged Starling
Waller´s Starling
Abbott´s Starling
Greater Blue-eared Starling
Sharpe s Starling

Old World Orioles (Oriolidae)
African Black-headed Oriole

Crows (Corvidae)
Pied Crow

Drongos (Dicruridae)
Fork-tailed Drongo

Bush-shrikes (Malaconotidae)
Black-fronted Bush-shrike
Northern White-crowned Shrike
Brown-crowned Tchagra
Black-crowned Tchagra

Fig. 11. The **Nubian Woodpecker** (*Campethera nubica*) is a common and medium-sized bird species of *Acacia* woodlands and savanna habitats, from sea level up to 2000 m a.s.l. **Nubian Woodpeckers** mostly feed alone, but keep in touch with their mate by frequent vocalizations. The food consists of insects and other invertebrates, which are taken from trees, but also from the ground. **Nubian Woodpeckers** therefore act as pest controllers in their environments. **Woodpeckers** (Picidae) in general, often drill holes into tree stems, while searching for insects. This behavior often creates cavities, which can later be used by other animals (e.g. other birds, bats). **Woodpeckers** are therefore very important for many ecosystems, as they enhance the structural richness of their environments and may even increase species richness (Photo: M. Vollstädt).

Sulphur-breasted Bush-shrike
Tropical Boubou
Black-backed Puffback

Shrikes (Laniidae)

Long-tailed Fiscal
Common Fiscal
Isabelline Shrike

Helmet-shrikes (Prionopidae)

White-crested Helmet-shrike
Batises and Wattle-eyes (Platysteridae)
Chin-spot Batis
Forest Batis

Old World Flycatchers and Chats (Muscicapidae)

African Dusky Flycatcher
African Grey Flycatcher
White-eyed Slaty Flycatcher
Pale Flycatcher
Spotted Flycatcher
Rüppell´s Robin Chat
Cape Robin Chat
White-starred Robin
Alpine Chat
Common Stonechat
Northern Wheatear
Pied Wheatear
Common Rock Thrush

Monarch-flycatchers (Monarchidae)

African Paradise-flycatcher
Blue-mantled Crested-flycatcher

Laughingthrushes (Leiotrichidae)

Arrow-marked Babbler

Thrushes (Turdidae)

Olive Thrush
Abyssinian Ground Thrush

Fig. 12. The **Montane White-eye** (*Zosterops poliogaster*) is a small bird, typically found in forests and forest edge at higher elevations. The **Montane White-eye** is considered omnivorous, as the species takes everything from invertebrates to nectar and fruit. The species is therefore crucial for high elevation ecosystems, as it acts as pest control, pollinator and seed disperser (Photo: C. Hemp).

Old World Warblers (Sylviidae)

Tawny-flanked Prinia
Yellow-breasted Apalis
Grey-backed Camaroptera
Willow Warbler
Blackcap
Brown Woodland Warbler
Hunter´s Cisticola
Evergreen Forest Warbler
Black-headed Apalis
Cinnamon Bracken Warbler
Bar-throated Apalis
Mountain Yellow Warbler
Common Whitethroat
Olivaceous Warbler
Trilling Cisticola
Winding Cisticola
Grey Wren-Warbler
African Hill-Babbler

White-eyes and Yuhinas (Zosteropidae)

Abyssinian White-eye
Montane White-eye

Crombecs and allies (Macrosphenidae)

Red-faced Crombec

Sunbirds (Nectariniidae)

Collared Sunbird
Amethyst Sunbird
Variable Sunbird
Bronze Sunbird
Eastern Double-collared Sunbird
Olive Sunbird
Scarlet-chested Sunbird
Beautiful Sunbird
Hunter´s Sunbird
Scarlet-tufted Malachite Sunbird
Tacazze Sunbird

Old World Sparrows (Passeridae)

Yellow-spotted Petronia
Rufous Sparrow
Grey-headed Sparrow

Fig. 13. The **Scarlet-tufted Malachite Sunbird** (*Nectarinia johnstoni*) is a highland species, found in moorlands above 3000 m a.s.l. The species forages mainly on nectar of *Protea* and *Lobelia*, which makes the **Scarlet-tufted Malachite Sunbird** important pollinators of highland ecosystems (Photo: C. Hemp).

Fig. 14. The **Amethyst Sunbird** (*Chalcomitra amethystina*) is a common and widespread bird, populating a variety of habitats from forest edge to woodlands and gardens and occurring from sea level to elevations of up to 2200 m a.s.l. **Amethyst Sunbirds** forage mostly for insects and thereby act as pest control agents. Like all sunbirds (Nectariniidae), they also feed on nectar, which they can access with their long, curved beaks. **Amethyst Sunbirds** hence also contribute to the pollination of various plant species (Photo: M. Vollstädt).

Whydahs and Indigobirds (Viduidae)
Pin-tailed Whydah
Straw-tailed Whydah
Eastern Paradise Whydah

Weavers (Ploceidae)
Taveta Golden Weaver
Red-headed Weaver
Baglafecht Weaver
Black-headed Weaver
Chestnut Weaver
White-browed Sparrow Weaver
White-headed Buffalo Weaver
Red-billed Buffalo Weaver
Lesser Masked Weaver
Red-billed Quelea
Yellow Bishop
White-winged Widowbird

Waxbills (Estrildidae)
Grey-headed Negrofinch
Village Indigobird
Abyssinian Crimsonwing
Red-billed Firefinch
Red-cheeked Cordon-bleu
Rufous-backed Mannikin
Bronze Mannikin
Yellow-bellied Waxbill
Jameson s Firefinch
Cut-throat Finch
Green-winged Pytilia

Old World Buntings (Emberizidae)
African Golden-breasted Bunting
Somali Golden-breasted Bunting
Cinnamon-breasted Rock Bunting

Finches (Fringillidae)
Yellow-crowned Canary
Yellow-fronted Canary
Yellow-rumped Seedeater
Oriole-Finch
Streaky Seedeater
African Citril

Fig. 15. The **Green-winged Pytilia** (*Pytilia afra*) is a small bird species, commonly found near ground in dense bush, thickets and scrub. Compared to other **Waxbills** (Estrildidae), the **Green-winged Pytilia** is less social and is usually observed in pairs. These birds mainly feed on the seeds of different grasses, but may temporarily forage almost exclusively for insects, especially for termites. **Green-winged Pytilias** are therefore also important for pest control (Photo: M. Vollstädt).

Fig. 16 (right below). The **Verreaux's Eagle-Owl** (*Bubo lacteus*) is also known as the **Milky Eagle Owl** is the largest African owl. The species is found at low elevations and prefers savanna vegetation. Like most owls (Strigidae), the **Milky Eagle Owl** is a nocturnal predator thanks to their excellent night vision and their very keen hearing. It is an important top predator in its environment, hunting mostly for small to medium-sized mammals, thereby helping to regulate their populations (Photo: C. Hemp).

Subproject 7

Effects of climate and land-use change on biodiversity and ecosystem functioning of pollinators and decomposers

by Marcell Peters, Alice Claßen & Ingolf Steffan-Dewenter

Bees, birds, and bats contribute to higher yields on coffee farms on Mt Kilimanjaro

A major aim of the KiLi subproject SP7 was to understand the contribution of animals as ecosystem service providers in coffee agriculture. Coffee is the most important cash crop in the Kilimanjaro region and grown by both large commercial companies and small-holder agricultural farms. The destruction of natural habitats in landscapes and the intensification of farming practises may lead to a loss of animals, and potentially in consequence, to a loss of beneficial ecosystem services like pest control or pollination of coffee plants. Experiments showed that where birds and bats had access to the plants, there was almost a ten percent higher fruit set compared to net-covered plants excluding larger animals as bats and birds. This is most likely down to the fact that the animals destroy pests that would otherwise feed on the coffee plants. This reduction in leaf damage probably leads to fewer coffee cherries falling from the tree before they are ripe. When looking at pollination we assumed a no strong contribution of bees and other insects as pollinators as the examined coffee variety, *Coffea arabica*, is also capable to self-pollinate. However, we found that if pollinators have access to the coffee blossoms, the cherries are around seven percent heavier, which signifies that the coffee is of higher quality. To conclude, the effects of pollination and pest control complement each other perfectly and contribute to yields: **birds and bats provide more cherries; bees and other pollinators ensure better quality of coffee.**

We advise to maintain stable habitats for a diversity of pollinators, birds and bats that contribute to coffee yields. This could be stable hedge rows or other natural and semi-natural habitats surrounding agricultural areas.

Fig. 1. Experimentally excluding insects with fine nets from coffee blossoms revealed the importance of bees for coffee bean quality (Photo: Alice Classen).

Fig. 2. By excluding birds and bat with large nets put around coffee bushes (blue) we could show the importance of vertebrates for the quantity of coffee beans (Photo: Alice Classen).

Temperature as a driver of bee diversity

The species diversity of animals strongly varies on earth. A major issue of the subproject SP7 was to find out how bee diversity varies along an elevational gradient and which factors are the main drivers of bee diversity. Wild bees are among the most important pollinators of our ecosystems and pollinate a majority of worlds' crops. To collect bees we placed coloured plastic soup bowls as artificial flowers on 60 study sites from the lowlands of Mt Kilimanjaro at 800 m to nearly 5000 m elevation. Sprayed with blue, yellow or white paint that reflects the light, the bowls attract bees which fly right into the trap containing water and soap. We found that the biodiversity of bees declines continuously with increasing altitude. However, even at the highest elevation bees could be found: a single species of apex-burrow bee (*Lasioglossum*, Halictidae) which occurs at extremely high abundances in the alpine vegetation zone. The bee uses good thermal conditions at cloud-free times of the day (with temperatures of ~20°C) to collect nectar and pollen. Importantly, we found that the diversity was not, as originally expected, strongly related to the availability of flowers in ecosystems. Instead, temperature seemed to regulate the accessibility of resources and is therefore more relevant than the availability of flower resources per se.

Fig. 3. Coloured soup bowls, which work as ‚artificial flowers' to collect bees (Foto: Alice Claßen).

Mammals at Mt Kilimanjaro

by Friederike Gebert, Marcell Peters & Ingolf Steffan-Dewenter

Mammals are of immense ecological importance and flagships for conservation. Today, large mammals are threatened by human disturbances such as habitat destruction and hunting and may increasingly depend on the conservation of protected areas. On Mt Kilimanjaro, we studied large mammals (> 10 kg) with camera traps which we installed on 66 study plots along an elevational gradient from 870 to 4550 m a.s.l. Our results showed that the species richness of mammals peaked at around 2500 m in the forest belt. Here, we encountered species like the **Common Duiker**, **Harvey's Duiker**, **Bushbuck**, **Suni**, **Bushpig**, **Honey Badger**, **Blue Monkey**, **Black-and-White Colobus**, **Crested Porcupine**, **Large-Spotted Genet** and **Serval**. A very exciting finding was that we could film the endangered antelope species **Abbott's Duiker** for the very first time on Mt Kilimanjaro. This elusive antelope is only found on some isolated mountain massifs in the East and South of Tanzania and until now, the distribution pattern of this antelope on Mt Kilimanjaro was not known. We documented the **Abbott's Duiker** throughout the forest belt from

Fig. 1. Pair of **Abbott's Duikers** foraging in disturbed *Ocotea* Forest (Fod2, 2470 m).

1900 to 3800 m. Perhaps Mt Kilimanjaro is another stronghold for this species?

Outside Mt Kilimanjaro National Park, we only found large mammals like the **Lesser Kudu**, **Bushbuck**, **Yellow Baboon** and **Plains Zebra** in protected habitats like the Lake Chala Conservation Area and not, for example, on other unprotected study sites in the savanna. This finding underpins the crucial importance of protected areas for the conservation of large mammals.

Fig. 2. Abbott´s Duiker, in the *Podocarpus* forest in the morning (Fpo2, 2940 m).

Fig. 3. Male **bushpig** checking its territory in disturbed *Ocotea* forest at night (Fod4, 2560 m).

Fig. 4. Pair of **Crested Porcupines** roaming in their territory (disturbed *Podocarpus* Forest, Fpd2, 2990 m).

Fig. 5. Ratel or **Honey Badger** looking for food in the *Podocarpus* Forest (Fpo5, 2800 m).

Fig. 6. Serval marking its territory (Disturbed *Podocarpus* Forest, Fpd4, 2820 m).

Fig. 7. Lesser Kudu wandering in the savanna of the Chala area at the eastern slopes of Mt Kilimanjaro in the early morning (Sav5, 951 m).

Mammal species at Mt Kilimanjaro

ORDER HYRACOIDEA

Family Procaviidae

1. **Eastern Tree Hyrax** (*Dendrohyrax validus*)

ORDER PRIMATES

Family Galagonidae

2. **Small-Eared Greater Gallago** (*Otolemur garnetti panganiensis*)

Family Cercopithecidae

3. **Yellow Baboon** (*Papio cynocephalus*)
4. **Hilgert's Vervet Monkey** (*Chlorocebus pygerythrus hilgerti*)
5. **Zanzibar Sykes's Monkey** (*Cercopithecus nicticans albogularis*)
6. **Black-and-White Colobus** (*Colobus guereza caudatus*)

ORDER RODENTIA

Family Sciuridae

7. **Zanj Sun Squirrel** (*Heliosciurus undulates*)

Family Leporidae

8. **African Savanna Hare** (*Lepus victoriae*)

Family Histricidae

9. **Crested Porcupine** (*Hystrix cristata*)

ORDER EULIPOTYPHLA

Family Erinaceidae

10. **Four-Toed Hedgehog** (*Atelerix albiventris*)

ORDER CARNIVORA

Family Felidae

11. **Serval** (*Leptailurus serval*)
12. **Leopard** (*Panthera pardus*)

Family Herpestidae

13. **Egyptian Mongoose** (*Herpestes ichneumon*)
14. **White-tailed Mongoose** (*Ichneumia albicauda ibeana*)

Family Viverridae

15. **African Civet** (*Civettictis civetta*)
16. **Large-spotted Genet** (*Genetta maculata*)

Family Canidae

17. **Side-striped Jackal** (*Canis adustus*)
18. **Golden Jackal** (*Canis aureus*)

Family Mustelidae

19. **Ratel** or **Honey Badger** (*Mellivora capensis*)

ORDER PERISSODACTYLA

Family Equidae

20. **Plains Zebra** (*Equus quagga boehmi*)

ORDER ARTIODACTYLA

Family Suidae

21. **Bushpig** (*Potamochoerus larvatus daemonis*)

Family Bovidae

22. **Harvey's Duiker** (*Cephalophus harveyi*)
23. **Abbott's Duiker** (*Cephalophus spadix*)
24. **Common Duiker** (*Sylvicapra grimmia hindei*)
25. **Suni** (*Nesotragus moschatus*)
26. **Kirk's Dik-Dik** (*Madoqua kirkii*)
27. **Bushbuck** (*Tragelaphus scriptus*)
28. **Lesser Kudu** (*Tragelaphus imberbis*)
29. **African Buffalo** (*Syncerus caffer*)

Fig. 8. Bushbaby (*Otolemur garnetti panganiensis*). Bushbabys are regarded as pests in the Chagga homegardens since they are thought to consume fruits. However, most of their diet consists of insects and thus they are important for pest control.

Diversity and taxonomy of millipedes from Mt Kilimanjaro

by Henrik Enghoff & Sara Frederiksen

Millipedes are a class (Diplopoda) of arthropods. Reaching body lengths of up to 30 cm, they are among the largest terrestrial invertebrates in the tropics. Ecologically they belong to the 'detritivores' who play vital roles in the decomposition of dead vegetable matter (leaf litter, dead wood etc.). Although earthworms are usually considered to be the most important terrestrial detritivores (along with termites in the tropics), millipedes sometimes account for a substantial share of decomposition. As an example, the widespread, red-legged East African "Mombasa train" (*Epibolus pulchripes*) is able to decompose "needle" litter from *Casuarina* trees which otherwise can be quite hard to get rid of.

Research on Kilimanjaro millipedes started with Sjöstedts expedition in 1905–1906. Since then, the species list has grown to 37 species, including 12 which were discovered for the first time on Kilimanjaro by Sara Frederiksen during the KiLi Project (Table 1).

Fig. 1. *Epibolus pulchripes*, one of the "Mombasa Trains". It is common, e.g., in the East Usambara Mountains (Photo: Claudia Hemp).

[1] http://www.cosy.sbg.ac.at/~zzspri/travels/BANweb/bantrail.html

Fig. 2. Ulf Pommer holding a "Mombasa Train", a common name for large millipedes. The size of the animal can be nicley estimated on this photo (Photo: Claudia Hemp).

Saras work has focused on two aspects:

- taxonomy, including description of new species
- diversity patterns, including effects of elevation and land-use

New species and a new genus

The taxonomic work has focused on the endemic Afrotropical family Odontopygidae, species of which are often abundant especially in savanna habitats and in cultivated areas where they occasionally are pests on such crops as cotton, peanuts and potatoes. In the genus *Aquattuor*, described by PhD student Sara Frederiksen on the basis of a species from the East Usambara Mts, a new species, *A. claudiahempae*, was found to be abundant on Mt Kilimanjaro. It was described together with several new species from the Udzungwa Mts, and a molecular phylogeny showed it to be very close to *A. fasciatus*, a species described from Zanzibar. It cannot be excluded that the two species are in fact the same, and that the occurrence of *A. claudiahempae* on Mt Kilimanjaro is due to inadvertent introduction by humans. This idea is in agreement with the fact that *A. claudiahempae* was almost exclusively found in coffee plantations and Chagga homegardens.

The taxonomy of Odontopygidae is very much in need of revision, and the genus *Rhamphidarpoides* was among the most poorly understood odontopygid genera. A revisionary study showed that a group of species formerly assigned to *Rhamphidarpoides* form a well-defined cluster, for which the genus name *Raduliverpa* was introduced and a new species described from Mt Kilimanjaro. On the other hand, the species previously known as *Odontopyge kilimandjarona*, one of the most abundant Kilimanjaro millipede species, was shown to belong in *Rhamphidarpoides* in the strict sense. There are still taxonomic problems with odontopygids from Mt Kilimanjaro. Notably, one of the largest species, "*Prionopetalum* n.sp. cf. *aculeatum*", remains to be analysed and described, although *Prionopetalum* is one of the best studied odontopygid genera.

Other problematic species belong to three families of tiny (a few mm long) flat-backed millipedes: Pyrgodesmidae, Ammodesmidae and Trichopolydesmidae. *Elassystremma* cf. *pongwe* belongs to Ammodesmidae, a small family of millipedes which can roll up in a perfect sphere, just like European pill millipedes (family Glomeridae). The species from Mt Kilimanjaro is probably different from *E. pongwe*, but more material is needed in order to as-

Fig. 3. A copulating pair of *Plethocrossus tardus*, a large species of Odontopygidae. The male (showing his partly red head) has twisted his body around the female and has inserted his gonopods (partly visible as a whitish structure next to the female's second segment) into the female. Mrusunga valley, submontane forest (Flm4) (Photo: Claudia Hemp).

certain that. *Sphaeroparia minuta* was previously known only from Mt Meru, and its occurrence on Mt Kilimanjaro constitutes a biogeographical link between these two volcanos.

Fig. 4. A flat-backed millipede (family Gomphodesmidae) from Mt Kilimanjaro, Chala area (Sav5). This species is common in savanna habitats in northern Tanzania (Photo: Claudia Hemp).

Diversity patterns

Quantitative samples of millipedes were obtained with pitfall traps placed in 26 plots covering an altitude range from 870 to 3900 m a.s.l. and a variety of habitat types: Chagga homegardens, coffee plantations, maize fields, grassland, savanna, lower montane forest, *Ocotea* forest, *Podocarpus* forest, *Helichrysum* vegetation, and *Erica* forest.

The pitfall sampling was supplemented with hand collecting. The diversity of millipedes on Mt Kilimanjaro is low compared with that seen in the much older Eastern Arc Mountains (Usambara, Uluguru, Udzungwa etc.), and the level of endemism (40%) is much lower. The highest species diversity was found at mid-altitudes, around 1600 m a.s.l. A negative correlation between body size and elevation as well as temperature was observed. Surprisingly, disturbed habitats had just as diverse millipede faunas as undisturbed ones. However, the body size of the millipedes in disturbed habitats tended to be smaller.

A parallel diversity study of ground beetles (family Carabidae) showed in part different patterns: the correlation between species richness and elevation was not significant; on the other hand a positive correlation with humidity was observed.

Table 1. Species of millipedes (Diplopoda) from Mt Kilimanjaro. Species discovered during the KiLi Project are marked with an asterisk (*).

ORDER POLYXENIDA

Family Polyxenidae

1. *Pauropsxenus brachyartema* (Brolemann, 1920)

ORDER STEMMIULIDA

Family Stemmiulidae

2. *Stemmiulus sjoestedti* (Attems, 1909)

ORDER SPIROSTREPTIDA

Family Odontopygidae

3. *Aquattuor claudiahempae* Enghoff & Frederiksen, 2015*
4. *Calyptomastix leviceps* (Attems, 1909)
5. *Haplothysanus polybothrus* Attems, 1909
6. *Harmomastix tetracanthus* Attems, 1909
7. *Harmomastix macracanthus* Attems, 1914*
8. *Plethocrossus octofoveatus* Attems, 1909
9. *Plethocrossus tardus* Attems, 1909
10. *Prionopetalum* n. sp. cf. *aculeatum* Attems, 1914*
11. *Prionopetalum serratum* Attems, 1909
12. *Prionopetalum tricuspis* Brolemann, 1920*
13. *Prionopetalum xerophilum* (Carl, 1909)
14. *Raduliverpa serpentispina* Frederiksen & Enghoff, 2014*
15. *Rhamphidarpoides kilimandjarona* (Attems, 1909)
16. *Syndesmogenus gracilis* Attems, 1909
17. *Syndesmogenus voiensis* (Ribaut, 1907)*
18. *Xystopyge* cf. *biacanthus* Frederiksen & Enghoff, 2012*

Fig. 5. *Calyptomastix leviceps* (Photo C Hemp)

Family Spirostreptidae

19. *Anastreptus scalatus* (Karsch, 1881)*
20. *Lophostreptus armatus* Pocock, 1896*
21. *Lophostreptus ptilostreptoides* Carl, 1909
22. *Thiangetastreptus montanus* (Attems, 1909)

ORDER POLYDESMIDA

Family Ammodesmidae

23. *Elassystremma* cf. *pongwe* Hoffman & Howell, 1981*

Family Gomphodesmidae

24. *Astrodesmus stellifer* Cook, 1896*
25. *Clastrotylus sjoestedti* Hoffman, 2005
26. *Kilimagomphus massaiensis* (Attems, 1938)
27. *Merodesmus compactilis* (Gerstaecker, 1873)

Family Oxydesmidae

28. *Ctenodesmus basilewskyi* Hoffman, 1990
29. *Ctenodesmus kibonotanus* (Attems, 1909)
30. *Lyodesmus fischeri* (Karsch, 1885)
31. *Proxenodesmus* n.sp.*

Family Paradoxosomatidae

32. *Eoseviulisoma julinum* (Attems, 1909)

Family Pyrgodesmidae

33. *Procoptodesmus diffusus* Brolemann, 1920
34. Genus? species? 1*
35. Genus? species? 2*

Family Trichopolydesmidae

36. *Sphaeroparia attenuata* Brolemann, 1920
37. *Sphaeroparia minuta* Attems, 1909*

Fig. 6. *Calyptomastix leviceps*, a relatively colourful species of Odontopygidae. Like many other odontopygids it wriggles violently when disturbed, instead of rolling up into a spiral like most millipedes (Photo: Claudia Hemp).

Fig. 7. *Prionopetalum kraepelini* – a typical species of Odontopygidae (Photo: A. Illum). **Fig. 8.** Sara Frederiksen, PhD student of SP7, working on millipedes.

Low contribution of invertebrates to decomposition of organic matter along an elevational gradient and a land-use gradient on the southern slopes of Mt Kilimanjaro

by Juliane Röder, David Schellenberger Costa, Tim Appelhans, Michael Kleyer, Thomas Nauss & Roland Brandl

The decomposition of organic matter is important for nutrient cycling and carbon fluxes and is therefore a major ecosystem service. Various groups of invertebrates can facilitate decomposition, but their contribution depends on climatic variables. In this study, we wanted to know how much invertebrates contribute to decomposition, as compared to climate and microbial organisms. We determined the decomposition of maize leaves in bags from which invertebrates were excluded or not. Invertebrates were mechanically excluded by using bags of a smaller mesh size or chemically excluded by adding naphthalene, a common chemical used as toilet air fresheners or moth balls which deters many arthropods. With this set-up, we were able to determine non-target effects of naphthalene and the effect of mesh size on decomposition rates. Along the elevational gradient on the slopes of Mt Kilimanjaro, decomposition rates were most influenced by humidity, temperature and the leaf economics spectrum of the local vegetation, with a peak at mid-elevations (ca. 2000 m a.s.l.) in undisturbed habitats; in disturbed habitats, decomposition rates linearly decreased as elevation increased. The 'leaf economics spectrum' summarizes characteristics of plants, in this case of the plants' leaves. Plants at one end of this spectrum are slow-growing, with high lignin and low nutrient contents, and they invest a lot of energy in mechanical and chemical plant defenses. At the other end of the spectrum, plants are growing fast, have a higher nutrient content and low plant defenses. Therefore, these latter plants have a higher palatability for both herbivores and invertebrate decomposers.

Along the land-use gradient, decomposition was highest in forest sites, followed by homegardens and coffee plantations, and only low decomposition rates in grassland sites. The differences in decomposition rates between the

Fig. 1. Litter bags with large mesh size (4 mm x 4 mm) allowed access of invertebrates, while litter bags with a small mesh size (20 µm x 20 µm) excluded them. Naphthalene was added to both large and small mesh bags to control for non-target effects of naphthalene and for potential climatic effects of different mesh sizes (Photo: Juliane Röder).

Fig. 2. Litter bags in a homegarden, two months after they were placed on the site (Photo: Juliane Röder).

different study sites were significantly higher at higher humidity and at sites with plants at the fast-growing end of the leaf economics spectrum. Invertebrates contributed only little to decomposition in undisturbed habitats. Their contribution decreased towards higher elevations as the contribution of microbial decomposers increased. Along the land-use gradient, there were no differences in the contribution of invertebrates to decomposition. Naphthalene had a negative effect on decomposition rates, and the magnitude was comparable to the positive contribution of invertebrates. Invertebrates facilitated decomposition only when both temperature and humidity were high. **Our results indicated that decomposition is controlled by humidity and temperature, but not invertebrates.** Furthermore, decomposition of our standard litter was faster on study sites where plants were on average faster growing, with higher nitrogen content and/or lower plant defenses. **This indicates that decomposer communities are more active on sites with a high turnover of biomass.**

Abundance of ground-living arthropods along the elevational gradient

by Juliane Röder, Florian Detsch, Insa Otte, Tim Appelhans, Thomas Nauss, Marcell K. Peters & Roland Brandl

Species diversity is the variable most commonly studied in recent ecological research. Ecological processes, however, are driven by individuals and affected by their abundances. Understanding the variation in animal abundances along climatic gradients is important for predicting changes in ecosystem processes under global warming. **High abundances make arthropods, despite their small body sizes, important actors in food webs**, yet abundance distributions of major arthropod taxa along climatic gradients remain poorly documented.

We sampled arthropod assemblages in disturbed and undisturbed vegetation types along an elevational gradient of 860–4550 m a.s.l. on the southern slopes of Mt Kilimanjaro, Tanzania. In our analysis, we focused on 13 taxa of arthropods that represented three major functional groups: predators (army ants, spiders, centipedes), herbivores (crickets & grasshoppers), and decomposers (springstails, woodlice, millipedes, termites). Five groups contained species with various or with mixed diets (beetles, mites, other ants, cockroaches, earwigs). **We expected the abundance of predators to decline faster than that of herbivores and decomposers, considering the loss of energy over at least two trophic levels** (plant → herbivore, herbivore → predator). However, we did not find support for the expectation that the abundance of predators would respond to elevation differently than other functional groups. **Abundance patterns were unimodal for most of the taxa and functional groups, including decomposer arthropods, and most of them peaked at low elevations in lower montane forest.** When we assigned beetles to functional groups, however, decomposer beetle abundances declined almost linearly, and abundances of predator beetles (ca. 2400 m a.s.l.) and herbivore beetles (ca. 3000 m a.s.l., undisturbed vegetation) peaked at higher elevations and exhibited unimodal patterns. Temperature, not primary productivity, was the best predictor of abundance for most of the taxa and groups. Disturbance was only of minor importance. Our results revealed different trends in the response

Fig. 1. This impressive carabid beetle (*Thermophilum hexastictum*) was collected in the savanna. It can defend itself by spraying formic acid towards an attacker – including curious biologists….

of arthropod abundance along the elevational gradient that depended on the level of taxonomic and functional resolution. **This highlights the need for more comparisons of different taxa along the same climatic gradients.**

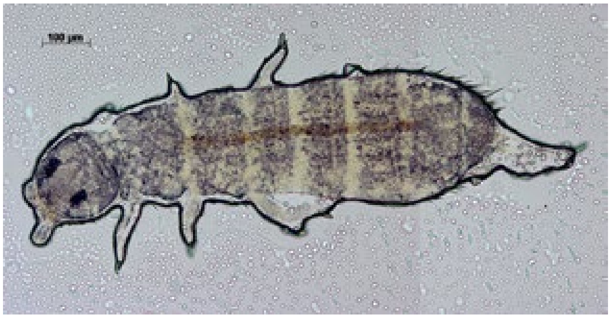


Fig. 2. Springtails were the most abundant group of invertebrates in the pitfall trap samples (here: *Cryptopygus thermophiles*, Photo Juliane Röder). Most of them are very small, but they are very abundant, which makes them important for decomposition processes.

Activity of soil fauna depends on soil humidity

by Juliane Röder & Roland Brandl

Soil invertebrates contribute to nutrient cycling in three different ways: as members of micro-foodwebs, as litter transformers and as ecosystem engineers. Springtails, mites and nematodes feed on bacteria and fungi, thereby regulating population densities of microorganisms, whereas some are directly involved in nutrient decomposition. Diplopods and other litter transformers multiply the surface of organic material and create favorable microclimatic conditions for microorganisms in their faecal pellets. Finally, earthworms and termites are main actors in the bioturbation of soil, resulting in improved ventilation and the translocation of soil. **The feeding activity of all three groups of invertebrates can increase the speed of decomposition**, as long as the activity of microbial decomposers is not limited by environmental conditions. We used bait lamina to estimate soil fauna

Fig. 3. Pitfall trap with roof against the sun and rain, on a grassland site (Photo: Juliane Röder).

Fig. 1. Bait lamina are plastic strips with holes. The holes are filled with a mixture of cellulose, wheat bran and active coal. After two weeks, we counted the number of pierced holes to calculate feeding rates, and therefore soil fauna activity. The blue markings represent the soil surface at the time of collection (Photo: Juliane Röder).

activity along the elevational gradient and along the land-use gradient in both wet and dry seasons. We expected to find a hump-shaped pattern of soil fauna activity along the elevational gradient, as soil fauna activity is limited by low soil moisture in the savanna, and by low temperatures at high elevations. **Moderate disturbance has been found to increase soil fauna activity, as well as high plant species diversity, high plant cover, the absence of mechanical tillage, pesticides and herbicides, and high abundances of springtails and earthworms.** Therefore, we expected to find the highest activity in homegardens, followed by grasslands and forests, and coffee plantations to have the lowest feeding rates. Soil fauna activity increased with elevation and was highest in *Erica* forests. **In the wet seasons, feeding rates were higher in maize fields compared to savanna sites, and in homegardens, coffee plantations and grasslands compared to forest sites at similar elevations.** The long dry season from June to September reduced soil fauna activity to a minimum: in some savanna and maize field sites, we could not detect any feeding activity. In the forest and in grassland sites, feeding rates were between 25% and 40% on average. In the homegardens, variation between sites was low, with feeding rates of 15-25%. Coffee plantations showed are wide range of feeding rates between 5% and 30%, depending on site conditions.

Humidity was most important for soil fauna activity. **Variation was large between sites of the same habitat type: feeding rates were related to soil humidity and vegetation cover rather than to plant species composition.**

Fig. 2. The bait lamina were placed in three different spots in the study site to cover differences in vegetation structure and therefore microclimate. It was very important to mark these spots, because the small grey strips were hard to find in most kinds of vegetation (here: a savanna site, Photo: Juliane Röder).

Fig. 3. The large amount of fieldwork was only possible with the help of our field assistants. At this *Helichrysum* site the installation of pitfall traps in the rocky ground was a challenge and had to be tested before we could distribute.

Fig. 4. PhD student Juliane Röder.

Amphibian diversity on Mt Kilimanjaro

(associate project 2)

by Giulia Zancolli

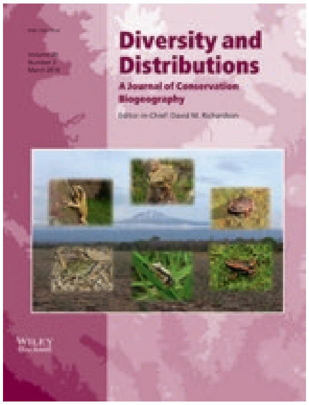
Amphibians are a unique group of vertebrates containing 7,858 known species and inhabiting the Earth for over 300 million years. Every year new species are described, especially from tropical regions. However, in the last two decades there has been an alarming number of extinctions placing amphibians among the most threatened group of animals, mainly because of habitat loss and an infectious disease called chitrydiomycosis.

A conspicuous number of herpetological surveys have been conducted in East Africa, especially in the Eastern Arc and adjoining coastal lowlands. Surprisingly, no systematic description of frog species occurring on Mt Kilimanjaro has been conducted before Giulia Zancolli's work in collaboration with the KiLi Project.

Chytridiomycosis

In addition to analysing patterns of diversity, we also tested for the presence of the fungal pathogen, *Batrachochytrium dendrobatidis*, which is causing mass extinction of amphibian species worldwide. Swab samples were collected from larvae of the two species of river frogs for the pathogen detection and both species resulted positive. The presence of this pathogen on Mt Kilimanjaro has serious implications considering that the fungus can be transported by footwear of hikers from contaminated water and soil and spread to other areas not only on Kilimanjaro but also the nearby Eastern Arc where endemic and vulnerable species may suffer drastic population declines.

Fig 1. Giulia Zancolli catching frogs.



Diversity and Distributions

A Journal of Conservation Biogeography

Fig. 3. Journal Cover of the journal Diversity and Distributions featuring Giulia Zancolli and colleagues' paper on amphibian diversity on Mt Kilimanjaro.

Figs. 2 (left) **& 3** (right). **Common Reed Frog** (*Hyperolius viridiflavus*) and **Fuelleborn´s Stream Frog** (*Strongylopus fuelleborni*).

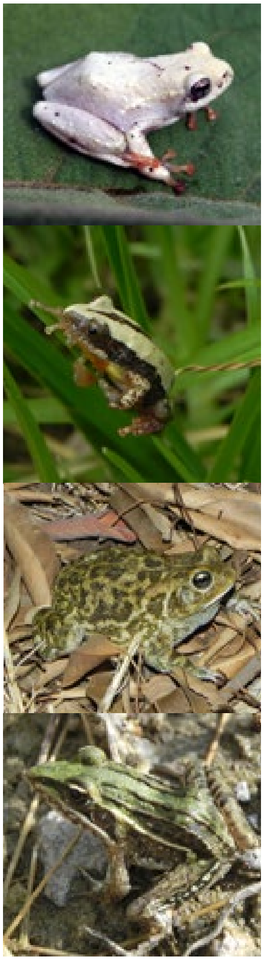
Figs. 4 (left) **& 5** (right). **Plimpton's Dainty Frog** (*Cacosternum plimptoni*) and the **Mascarene Grass Frog** (*Ptychadena mascareniensis).*

Table 1. List of species recorded on the southern slope of Mt Kilimanjaro. Reproductive modes are simplified and referred to the behaviors observed during the field work. When two modalities are observed for one species, letters are reported in order of observed frequency.

Species	Reproductive mode*	Habitat type**	Number of sites	Bioclimatic zone
Arthroleptidae				
Arthroleptis stenodactylus	C	CO/HO	5	submontane
Leptopelis bocagii	A[1]	SA	1	colline
Bufonidae				
Amietophrynus garmani	A	SA	1	colline
Amietophrynus gutturalis	A,B	SA/MA/CO/HO	12	colline, submontane
Hemisotidae				
Hemisus marmoratus	A[1]	SA/MA	3	colline
Hyperoliidae				
Afrixalus septentrionalis	A[2]	MA	1	colline
Hyperolius viridiflavus	A	MA/HO	4	colline, submontane
Kassina senegalensis	A	SA/MA	2	colline
Microhylidae				
Phrynomantis bifasciatus	A	MA	1	colline
Phrynobatrachidae				
Phrynobatrachus acridoides	A	SA	1	colline
Phrynobatrachus bullans	A	SA/MA	2	colline
Phrynobatrachus natalensis	A	MA	1	colline
Pipidae				
Xenopus victorianus	A,B?	HO	1	submontane
Ptychadenidae				
Ptychadena anchietae	A	SA/MA/CO	6	colline, submontane
Ptychadena mascareniensis	A	SA/MA/CO/HO	7	colline, submontane
Pyxicephalidae				
Amietia angolensis	B,A	CO/HO/FE	8	submontane
Amietia wittei	B,A	EF/MF/ES	11	montane
Cacosternum plimptoni	A	MA	1	colline
Strongylopus fuelleborni	A,B	EF/MF	6	montane
Tomopterna tuberculosa	A	SA	2	colline
Rhacophoridae				
Chiromantis petersii	A	SA/MA	2	colline

*Reproductive modalities: **A** = eggs and tadpoles in lentic waters, with the exception of: (1) eggs terrestrial and (2) eggs on plants above the water; **B** = eggs and tadpoles in lotic waters; **C** = eggs terrestrial (direct development).

**Abbreviated letters represent different habitat types: MA = maize, SA = savanna, CO = coffee plantation, HO = homegarden, EF = forest edge, MF = montane forest, ES = *Erica* shrubs.



Figs. 6–9. Above to below: **Common Reed Frog** (*Hyperolius viridiflavus*), **Forest Banana Frog** (*Afrixalus septentrionalis*), **Garman´s Toad** (*Amietophrynus garmani*), **Angolan River Frog** (*Amietia angolensis*).

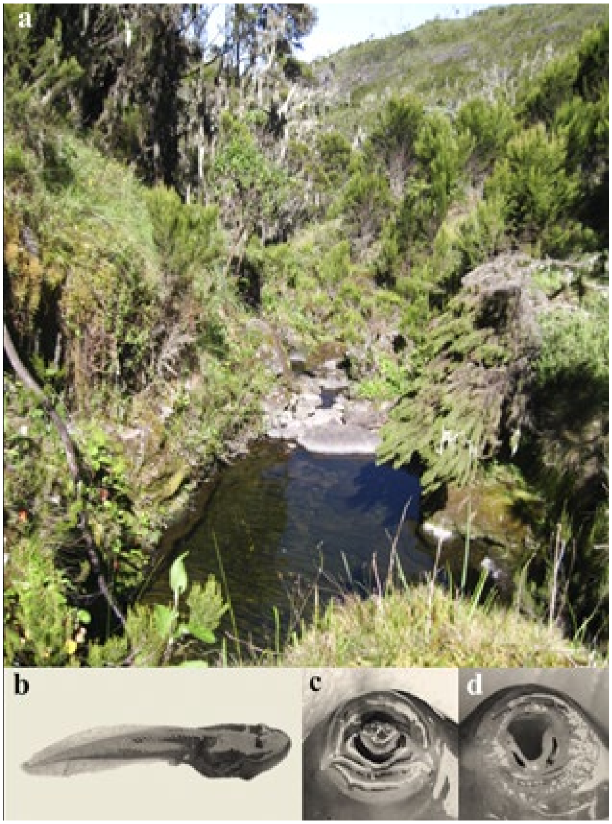


Fig. 10 (above). *Amietia angolensis* juvenile (upper corner) and larvae (below). On the right, a typical site at ca. 1750 m near the forest edge and the national park border. Tadpoles can be found in proximity of the river bank or in stream pool armoured by rocks and gravel.

Fig. 11 (right). Typical creek within the subalpine zone at ca. 3000 m, Kilimanjaro National Park, Tanzania; **a:** breeding site of *Amietia wittei* close to the Machame Huts campsite where porters collect water; **b:** larvae of *Amietia wittei*; **c:** oral disc with unchanged morphology; **d:** mouthparts with depigmentation of jaw sheaths and labial teeth.

Figs 12 & 13. The **Guttural Toad** (*Amietophrynus gutturalis*), left bottom, at Lake Chala, East Kilimanjaro and the **Senegal Running Frog** (*Kassina senegalensis*), right image bottom, a wide-spread species in tropical Africa (Photos C. Hemp).

Land Snails and Slugs (Gastropoda) of Mt Kilimanjaro

by Christine Fishaa Ngereza, Juliane Röder & Roland Brandl

Land snails occur in many terrestrial habitats throughout the climatic range. These animals are an important food source for various organisms and contribute to soil production, nutrient cycling and calcium concentration. Land snails react sensitively to changes of environmental conditions. This includes anthropogenic disturbance, changes in soil pH, calcium carbonate content in the upper soil layer, vegetation cover, and the presence/absence of structural elements in their habitat, such as stems of tall plants, which serve as aestivation sites, or pieces of stone under which they may hide. Most land snails can disperse actively just a few meters per year in a favourable habitat. As a consequence of this low vagility determinants of snail species richness may vary strongly at a spatial scale. Many species have narrow ecological niches, with significant changes of species richness and abundance over a few meters.

Land snail data for Mt Kilimanjaro and their localities were obtained from various published sources and mollusc collections of various museums (Tervuren, Belgium, Wales, U.K.). The major source of information was a revised list of the non-marine molluscs of East Africa. These data were complemented by our own field work between 2012-2013. We sampled in twelve habitats on the southern slopes of Kilimanjaro (Table 1). In each habitat type snails were sampled on 5 sites of 50 m x 50 m using a combination of standardized timed direct search and a litter sieving method. Data collected include number of species, habitat in which the species were collected, elevation and number of individuals of each species. Specimens collected are deposited in the Museum and House of Culture Dar es Salaam – National Museum of Tanzania.

A total of 81 species and morphospecies belonging to 17 families are known for Kilimanjaro. 30 species are known to be endemic to Kilimanjaro and another five restricted to the Mts Kilimanjaro/Meru area. During our survey 60 species were collected, with one species *Atoxon* near *kiboense* new to science. 11 species were documented for the first time to occur on Kilimanjaro. Seven species could not be identified to species level.

There was not a single species which was found in all habitat types. Only two species – the slug *Polytoxon robustum* (Simroth) and a snail *Trochonanina* (*Montanobloyetia*) *simulans* ssp. *simulans* (von Martens) were found in at least 8 habitat types. Four species were only found between 2100-4500 m in *Ocotea*, *Podocarpus* and *Erica* forest and *Helichrysum* vegetation.

Fig. 1. Slug *Polytoxon robustum* (family Urocyclidae), homegarden area Kidia, 1430 m (Photo: Claudia Hemp).

Fig. 2. *Subuliniscus alticola*, a **Subuluid snail**, found in *Ocotea* forest along the Marangu Route. This species is endemic to Kilimanjaro (Photo: Claudia Hemp).

Table 1. Checklist of species (n=81) of land snails and slugs recorded on Mt Kilimanjaro: Mai (maize farms), Sav (savanna woodlands), Flm (lower montane forest), Gra (submontane grassland), Hom (Chagga homegardens), Cof (coffee plantation), Foc (*Ocotea* forest), Fod (*Ocotea* forest disturbed), Fpo (*Podocarpus* forest), Fpd (*Podocarpus* forest disturbed), Fer (*Erica* forest), Hel (*Helichrysum* vegetation).

Meters a.s.l.		800-1100		1100-2000				2100-2800		2800-3100		3500-4000	4000-4500
Family	Species	Mai	Sav	Gra	Hom	Cof	Flm	Foc	Fod	Fpo	Fpd	Fer	Hel
Bradybaenidae	*Halolimnohelix meruensis* (d'Ailly)						■			■	■		
	Haplohelix alticola (d'Ailly)							■	■			■	■
	Haplohelix kilimae (Martens)									■		■	
	Haplohelix rufofusca (von Martens)				■		■	■	■	■	■		
	Vicariihelix verdcourti (Verdcourt)				■		■	■	■	■	■		
	Vicariihelix sp. A												
	Vicariihelix sp. B												
Vitrinidae	*Vitrina nigrocinta* (von Martens)							■	■	■	■	■	
	Vitrina kiboshoensis (d'Ailly)									■	■	■	
	Vitrina viridisplendens (d'Ailly)										■	■	■
	Vitrina ericinellae (d'Ailly)										■	■	
Urocyclidae	*Polytoxon robustum* (Simroth)			■	■	■	■	■	■	■			
	Leptichnus fischeri (Simroth)				■	■	■						
	Atoxon nr. kiboense				■								
	Atoxon kiboense (Verdcourt)				■								
	Bukobia sp. A				■								
	Trochozonites plicatula (Martens)		■		■		■	■					
	Thapsia radiata (d'Ailly)				■		■	■	■	■	■		
	Thapsia kibotonoensis (d'Ailly)		■			■	■		■		■		
	Chlamydarion volkensi (Thiele)				■		■						
	Trochonanina obstusangula (von Martens)		■	■	■	■							
	Trochonanina (*Montanobloyetia*) *simulans* ssp. *simulans* (von Martens)			■	■	■	■	■	■	■	■		
	Trochonanina membranacea (d'Ailly)				■		■						
	Trochozonites sp.												
Achatinidae	*Limicolaria martensiana* (Smith)				■	■	■	■	■	■			
	Limicolaria sjoestedti (d'Ailly)			■		■	■			■			
	Limicolaria volkensii (Martens)									■	■		
	Achatina (*Lissachatina*) *zanzibarica kilimae* (Dautzenberg)			■	■	■	■						
	Achatina (*Lissachatina*) *fulica* ssp. *bloyeti* (Bourgignat)	■	■	■	■	■							
Subulinidae	*Curvella kretschmeri* (von Martens)		■			■							
	Subuliniscus alticola (d'Ailly)						■	■	■	■	■		
	Subuliniscus chiradzuluensis (Smith)				■		■	■	■	■	■		
	Opeas sp. A					■	■			■			
	Pseudopeas sp. A				■	■	■		■				
	Subulina monticula (Pfeifer)						■	■	■	■			
	Subulina sp. A												
Endododontidae	*Punctum kilimanjaricum* (Verdcourt)				■	■	■		■	■			
	Trachycystis lamelosa (Pfeifer)				■	■							
Maizanidae	*Maizania volkensii* (von Martens)			■	■		■	■	■	■	■		
	Maizania hildebrandti kibotonoensis (d'Ailly)				■		■	■	■	■	■		
Vertigidae	*Gastrocopta jeanneli* (Germain)		■							■			

Meters a.s.l		800-1100			1100-2000			2100-2800		2800-3100		3500 – 4000	4000-4500
Family	Species	Mai	Sav	Gra	Hom	Cof	Flm	Foc	Fod	Fpo	Fpd	Fer	Hel
	Truncatellina flavogilva (Germain)		■										
Pomatidae	*Tropidophora* (*Octopoma*) *anceps* (Martens)		■					■					
Ferussaciidae	*Cecilioides* sp. A					■							
	Cecilioides sp. B		■										
Enidae	*Edouardia sordidula* (von Martens)		■										
	Conulinus daubenbergeri (Dautzenberg)				■		■	■	■	■	■		
	Cerastus bambuseti theeli (d'Ailly)											■	
Hydrocenidae	*Hydrocena tanzaniensis* (Verdcourt)						■						
Helicarionidae	*Kaliella barrakporensis* (Pfeifer)				■		■						
Streptaxidae	*Gonaxis* (*Macrogonaxis*) *ennoides* (von Martens)				■		■						
	Edentulina montium (d'Ailly)							■	■	■	■	■	■
	Gulella olkokolae (Adam)				■		■	■	■	■			
	Gulella bicarinata (Blume)							■		■	■		
	Gulella tudes (von Martens)				■		■	■	■	■	■		
	Gulella percivali kilimae (Preston)			■		■		■		■			
	Gulella simplicima (Preston)								■	■	■		
	Gulella lacuna (Preston)				■		■						
	Gulella handeiensis (Verdcourt)				■								
	Gulella coarctata (d'Ailly)		■							■			
	Gulella cf. pretiosa (Preston)		■										
	Gulella (*Juventigulella*) *spinosa* (Tattersfield)				■			■					
	Gulella noltei (Boettger)		■										
	Gulella conicodentata (Pfeifer)		■										
	Gulella micans (Pfeifer)												
	Gulella albogilva (Germain)		■										
	Gulella sp. A						■		■	■	■		
	Gulella sp. B				■								
	Gulella sp. C		■					■	■				
	Gulella sp. D						■		■	■	■		
	Gulella sp. E				■						■		
	Streprostele (*Raffraya*) *kilimanjaroensis* (Blume)				■	■	■	■	■	■	■		
	Streprostele cf. acicula (Morelet)		■										
	Streprostele sp. A (Adam)												
	Streprostele sp. C (Adam)												
	Tyloria sp. A												
Valloniidae	*Acanthinula* sp.												
	Pupoides coenopictus (Hutton)		■					■		■			
	Pupisoma sp.												
Euconulidae	*Guppya rumrutiensis* (Preston)							■					
Succineidae	*Succinea* sp.		■										

Species names in red mark molluscs endemic to Mt Kilimanjaro, names in blue are species endemic to Mts Kilimanjaro and Meru.

Figs. 3 & 4. *Trochonanina simulans simulans*, Urocyclid snails. This species occupies a broad ecological niche on Kilimanjaro. We found it in grasslands, coffee plantations, homegardens and throughout the forest belt (Photos: Claudia Hemp).

Fig. 5 (left). A **Bush snail**, probably *Haplohelix rufofusca*, from the North Pare Mountains, a mountain range located adjacent to Kilimanjaro (Photo: Claudia Hemp)

Figs. 6–8. Glass snails of the genus *Vitrina* (family Vitrinidae). Above: *V. kiboshoensis*, afroalpine zone on *Lobelia.* Middle: *V. ericinellae*, *Ocotea* forest Marangu at about 3200 m. Below: *V. viridisplendens*, submontane forest, Mrusunga valley at 1600 m (Photos: Claudia Hemp).

Grasshoppers & Bushcrickets as bioindicators and to illuminate regional and large scale speciation patterns in Africa

by Claudia Hemp (& field assistant Erick Materu)

Research on grasshoppers, locusts and bushcrickets (Insect order Orthoptera) in East Africa was started about 1996 and continued in the frame of the KiLi Project. Numerous new taxa were newly described highlighting the still high number of undiscovered species, especially in Tanzania. Thus, from 2001 onwards a new subtribe of Conocephalinae including 4 new genera and over 30 new species was erected, for other Orthoptera 15 new genera, about 130 new species and 4 subspecies were described. Checklists of Orthoptera were compiled for Mt Kilimanjaro (grasshoppers and locusts in 2009 and for bushcrickets in 2013). Further, annotated lists of Orthoptera were compiled for the East Usambara Mountains (2013) and for Kazimzumbwi Forest Reserve (2017). These checklists serve as basic data and are tools to assess for example the biodiversity on Orthoptera of a given area and to know about the share of endemic or threatened species.

Many Orthoptera species have a narrow ecological niche and are restricted to well defined plant assemblages and can thus be used as bioindicators, useful tools to identify habitats deserving protection. The presence of e.g. *Tropidonotacris grandis*, the **Great Ridgeback**, indicates dry deciduous forest or "Obstgartensteppe", two habitat types highly endangered by habitat destruction in Tanzania. The Phaneropterinae *Parapyrrhicia acutilobata*, the **Pointed Glinting Eye**, on the other hand indicates lowland wet forest, a forest type of which only few patches remain in East Africa.

Fig. 1. Female of the **Great Ridgeback** (*Tropidonotacris grandis*), a bioindicator of deciduous dry forest in East Africa.

If coastal forest is opened up or converted to grasslands the faunistic composition changes completely, mostly endemic and often flightless forest species are replaced by wide-spread and mainly fully mobile taxa. Forests such as Kazimzumbwi Forest are irreplaceable archives to understand large scale biodiversity patterns as was discussed for the genus *Pseudotomias*, a genus described from this forest having its closest relatives probably in West Africa. The discovery of the genus *Pseudotomias* implies that there must have been a more or less continuous forest cover connecting East and West Africa, otherwise related flightless and forest bound taxa could not have spread over such an enormous distance. Thus, the last patches of e.g. lowland forest serve as a precious data resource helping to understand biogeographical patterns of plant and animal taxa and to illuminate large scale speciation patterns in tropical Africa.

Fig. 2. The **Pointed Glinting Eye** (*Parapyrrhicia acutilobata*) is adapted to lowland wet forest. Only a couple populations are known for this well camouflaged leaf-like bushcricket species, e.g. in Kazimzumbwi Forest Reserve and on Zanzibar.

Drivers of the high biodiversity in the area were shown for flightless Orthoptera to be climatic fluctuations of the past creating numerous closely related species of various genera in geologically young and old mountain ranges in East Africa during the past 1–2 million years.

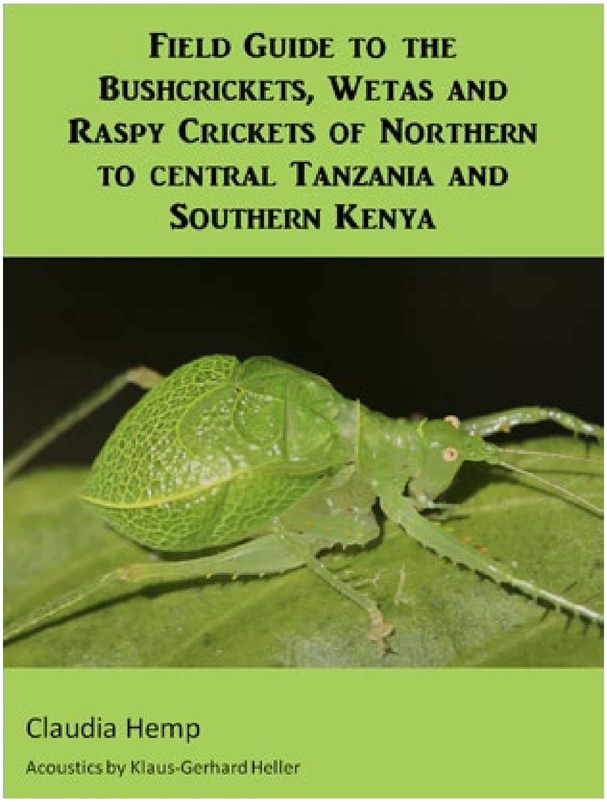
Fig. 3. Male and female of the **Kisarawe False-Leaf** (*Pseudotomias kisarawe*). The genus and two species were described 2017 from Kazimzumbwi Forest Reserve and the East Usambara Mountains. Further new species to science occur on various Eastern Arc Ranges such as the Udzungwa Mountains. As **Glinting Eyes** (*Parapyrrhicia*) **False-Leafs** are bioindicators since they are restricted to lowland and submontane wet forests.

Fig. 4. The **Inflated Tree Bushcricket** (*Euryastes jagoi*) is an archaeo-endemic of the Usambara Mountains – a witness of the old geological age of these world-wide recognized hotspots of biodiversity and endemism.

Flightless organisms with a limited mobility either adapt to certain habitats when climatic conditions change their environment or go extinct. Thus, in the geologically old Eastern Arc Mountains a mix of neo- and archaeo-endemics in Orthoptera was found while on geologically young mountains only neo-endemics were present. Thus, molecularly and morphologically closely related arrays of species were found to be the result of a rather recent speciation of the past 1-2 million years since sister taxa were also present on geologically young volcanoes such as Mt Kilimanjaro, Mt Meru or Mt Hanang even if they also occurred on the geologically old Eastern Arc Mountains. On the other hand monotypic genera such as *Euryastes* in the Usambara Mountains are probably archaeo-endemics since no close relatives are known for this curious canopy dweller. This bushcricket taxon survived in the Usambara Mountains due to the old age of these mountains and a permanent forest cover. These findings highlight the importance of forests as areas of a high biodiversity and home to many species yet to be discovered.

The findings of this research are currently compiled to publish a series of handbooks on East African grasshoppers & locusts (Jago´s Grasshoppers of East and North East Africa) started by the late Orthopterologist Nick Jago. Volumes 1-3 are already published. To be ordered at: http://www.blurb.com/b/7826846-jago-s-grasshoppers-of-east-and-north-east-africa, http://www.blurb.com/b/7789277-jago-s-grasshoppers-of-east-and-north-east-africa) and http://www.blurb.com/b/8845563-jago-s-grasshoppers-locusts-of-east-and-north-east. A Field Guide on the Bushcrickets, Wetas and Raspy Crickets of northern to central Tanzania and southern Kenya is in preparation. Thus, our research on Orthoptera resulted in checklists, handbooks and a field guide contributing to the knowledge of the high biodiversity of Tanzania.

Fig. 5. Balloons (*Aerotegmina*) are restricted to East Africa. Five species are known at present. Here the large **Whistling Balloon** (*A. vociferator*) is shown occurring in the Udzungwa and Nguru Mountains. Species of *Aerotegmina* produce one of the loudest songs known in insects.



FIELD GUIDE TO THE BUSHCRICKETS, WETAS AND RASPY CRICKETS OF NORTHERN TO CENTRAL TANZANIA AND SOUTHERN KENYA

Claudia Hemp

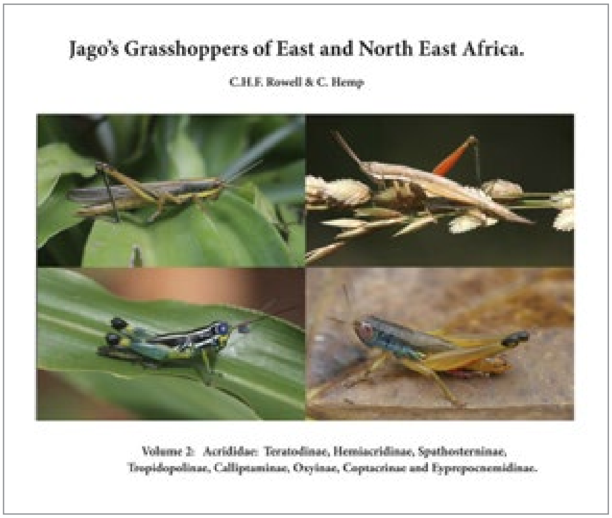
Acoustics by Klaus-Gerhard Heller

Fig. 6. Cover of planned Field Guide of Bushcrickets, Wetas and Raspy Crickets of Tanzania and southern Kenya. The range of this guide covers northern Tanzania and southern to central Kenya, coastal Tanzania and many species of central Tanzania. Keys for all genera and to most species are given. Over 230 species of Bushcrickets or Katydids, Wetas and Raspy Crickets are treated in this guide. Many species were photographed alive for the first time and data on their bioacoustics and nymphal development as well their biogeography and habitat are provided.

Jago's Grasshoppers of East and North East Africa.

C.H.F. Rowell, C. Hemp, & A. W. Harvey

Volume 1: Pneumoridae, Pyrgomorphidae, Lentulidae, Pamphagidae and Dericorythidae.

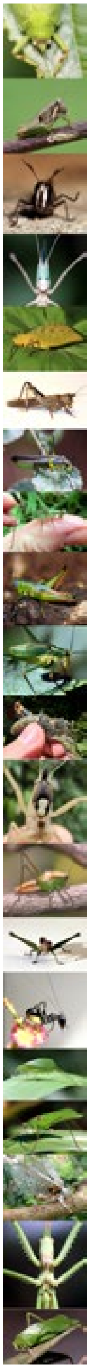


Jago's Grasshoppers of East and North East Africa.

C.H.F. Rowell & C. Hemp

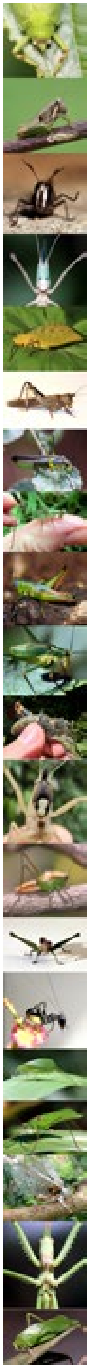
Volume 2: Acrididae: Teratodinae, Hemiacridinae, Spathosterninae, Tropidopolinae, Calliptaminae, Oxyinae, Coptacrinae and Eyprepocnemidinae.

Figs 7 & 8. Volumes 1 and 2 of the handseries books "Jago´s Grasshoppers of East and North East Africa" published in 2015 and 2017. Volume 3, covering the Acridid subfamily Catantopinae, was published in July 2018. At least three more volumes must be compiled to cover the grasshoppers and locusts of the area.



Alphabetical list of grasshoppers, locusts and bushcrickets (Orthoptera) of Kilimanjaro

Species	**Subfamily**	**Family**
Abisares depressus	Catantopinae	Acrididae
Abisares viridipennis	Catantopinae	Acrididae
Acanthacris ruficornis	Cyrtacanthacridinae	Acrididae
Acanthoscirtes albostriatus	Conocephalinae	Tettigoniidae
Acauloplax exigua	Pseudophyllinae	Tettigoniidae
Acorypha glaucopsis	Calliptaminae	Acrididae
Acorypha lacticosta	Calliptaminae	Acrididae
Acorypha nigrovariegata	Calliptaminae	Acrididae
Acoryphas reducta	Calliptaminae	Acrididae
Acrida bicolor	Acridinae	Acrididae
Acrida sulphuripennis	Acridinae	Acrididae
Acridoderes laevigatus	Cyrtacanthacridinae	Acrididae
Acrotylus furcifer	Oedipodinae	Acrididae
Acrotylus meruensis	Oedipodinae	Acrididae
Acrotylus ndoloi	Oedipodinae	Acrididae
Acrotylus patruelis	Oedipodinae	Acrididae
Acrotylus trifasciatus	Oedipodinae	Acrididae
Aerotegmina kilimandjarica	Hexacentrinae	Tettigoniidae
Afroagraecia brachyptera	Conocephalinae	Tettigoniidae
Afroanthracites montium	Conocephalinae	Tettigoniidae
Afroneanias scheffleri	Gryllacridinae	Gryllacrididae
Ailopus longicornis	Oedipodinae	Acrididae
Ailopus meruensis	Oedipodinae	Acrididae
Ailopus thalassinus	Oedipodinae	Acrididae
Allotriusia luteipennis	Catantopinae	Acrididae
Altihoratosphaga montivaga	Phaneropterinae	Tettigoniidae
Altiusambilla modicicrus	Lentulinae	Lentulidae
Ametroides kibonotensis	Gryllacridinae	Gryllacrididae
Ametroides nigrifacies	Gryllacridinae	Gryllacrididae
Amytta kilimandjarica	Meconematinae	Tettigoniidae
Amytta olindo	Meconematinae	Tettigoniidae
Amytta savannae	Meconematinae	Tettigoniidae
Anacridium wernerellum	Cyrtacanthacridinae	Acrididae
Anoedopoda lamellata	Mecopodinae	Tettigoniidae
Arantia fasciata	Phaneropterinae	Tettigoniidae
Atractomorpha acutipennis		Pyrgomorphidae
Aulacobothrus dorsatus	Gomphocerinae	Acrididae
Brachycatantops emalicus	Catantopinae	Acrididae
Brachycrotaphus sjostedti	Gomphocerinae	Acrididae
Brachycrotaphus tryxalicerus	Gomphocerinae	Acrididae
Cannula gracilis	Acridinae	Acrididae
Cataloipus oberthuri	Eyprepocnemidinae	Acrididae
Catantops momboensis	Catantopinae	Acrididae
Catoptropteryx aurita	Phaneropterinae	Tettigoniidae
Chortoscirtes meruensis	Conocephalinae	Tettigoniidae
Chortoscirtes ps.meruensis	Conocephalinae	Tettigoniidae
Chromothericles kanga		Thercleidae
Chrotogonus hemipterus		Pyrgomorphidae
Clonia jagoi	Saginae	Tettigoniidae
Conocephalus conocephalus	Conocephalinae	Tettigoniidae
Conocephalus iris	Conocephalinae	Tettigoniidae
Conocephalus maculatus	Conocephalinae	Tettigoniidae
Coryphosima stenoptera	Acridinae	Acrididae
Cymatomera viridimaculata	Pseudophyllinae	Tettigoniidae
Cyrtacanthacris tatarica	Cyrtacanthacridinae	Acrididae
Diabolocatantops axillaris	Catantopinae	Acrididae
Dictyophorus griseus		Pyrgomorphidae
Diogena fausta	Phaneropterinae	Tettigoniidae
Ducetia punctipennis	Phaneropterinae	Tettigoniidae
Duronia chloronota	Acridinae	Acrididae
Epacrocatantops curvicercus	Catantopinae	Acrididae
Eucoptacra gowdeyi	Coptacrinae	Acrididae
Eucoptarca exigua	Coptacrinae	Acrididae
Eugasteroides loricatus	Hetrodinae	Tettigoniidae
Eupropacris vana	Catantopinae	Acrididae
Eurycorypha combretoides	Phaneropterinae	Tettigoniidae
Eurycorypha conclusa	Phaneropterinae	Tettigoniidae
Eurycorypha curviflava	Phaneropterinae	Tettigoniidae
Eurycorypha meruensis	Phaneropterinae	Tettigoniidae
Eurycorypha punctipennis	Phaneropterinae	Tettigoniidae
Eurycorypha resonans	Phaneropterinae	Tettigoniidae
Eurycorypha varia	Phaneropterinae	Tettigoniidae
Euschmidtia sp.		Eumastacidae
Eyprepocnemis plorans	Eyprepocnemidinae	Acrididae
Fulvoscirtes fulvus	Conocephalinae	Tettigoniidae
Fulvoscirtes kilimandjaricus	Conocephalinae	Tettigoniidae
Fulvoscirtes legumishera	Conocephalinae	Tettigoniidae
Fulvoscirtes sylvaticus	Conocephalinae	Tettigoniidae
Gastrimargus africanus	Oedipodinae	Acrididae
Gastrimargus determinatus	Oedipodinae	Acrididae
Gastrimargus verticalis	Oedipodinae	Acrididae
Glomeremus falcifer	Gryllacridinae	Gryllacrididae
Glomeremus kilimandjaricus	Gryllacridinae	Gryllacrididae
Gonatoxia maculata	Phaneropterinae	Tettigoniidae
Gymnobothrus cruciatus	Acridinae	Acrididae
Gymnobothrus flaviventris	Acridinae	Acrididae
Gymnobothrus t. flexuosus	Acridinae	Acrididae
Gymnobothrus levipes	Acridinae	Acrididae
Gymnobothrus lineaalba	Acridinae	Acrididae
Gymnobothrus longicornis	Acridinae	Acrididae
Gymnobothrus t. temporalis	Acridinae	Acrididae
Hadrolecocatantops kilim.	Catantopinae	Acrididae
Hemiacris fervens	Hemiacridinae	Acrididae
Heteracris coerulescens	Eyprepocnemidinae	Acrididae
Heteracris juliea	Eyprepocnemidinae	Acrididae
Heteropternis couloniana	Oedipodinae	Acrididae
Heteropternis pugnax	Oedipodinae	Acrididae
Heteropternis thoracica	Oedipodinae	Acrididae
Horatosphaga heteromorpha	Phaneropterinae	Tettigoniidae
Humbe tenuicornis	Oedipodinae	Acrididae
Ischnansis curvicerca	Catantopinae	Acrididae
Ixalidium sjostedti	Catantopinae	Acrididae
Jasomenia sansibara	Oedipodinae	Acrididae
Rhabdoplea munda	Acridinae	Acrididae
Lamecosoma inermis	Phaneropterinae	Tettigoniidae
Leptacris monteiroi	Hemiacridinae	Acrididae
Lobopoma ambages	Acridinae	Acrididae
Lobosceliana femoralis		Pamphagidae
Locusta migratoria	Oedipodinae	Acrididae



Lophothericles carinifrons		Thercleidae
Lophothericles kongoni		Thercleidae
Lunidia viridis	Phaneropterinae	Tettigoniidae
Maura lurida		Pyrgomorphidae
Mecostibus sellatus		Lentulidae
Megalotheca longiceps	Conocephalinae	Tettigoniidae
Melanoscirtes kibonotensis	Conocephalinae	Tettigoniidae
Melidia laminata	Phaneropterinae	Tettigoniidae
Meruana usambarica	Hemiacridinae	Acrididae
Mesopsis laticornis	Gomphocerinae	Acrididae
Metaxymecus gracilipes	Eyprepocnemidinae	Acrididae
Minihippus reductus	Gomphocerinae	Acrididae
Monticolaria kilimandjarica	Phaneropterinae	Tettigoniidae
Morphacris fasciata	Oedipodinae	Acrididae
Niphetogryllacris kilim.	Gryllacridinae	Gryllacrididae
Niphetogryllacris meruensis	Gryllacridinae	Gryllacrididae
Ochrilidia gracilis njuki	Gomphocerinae	Acrididae
Odontomelus brachypterus	Acridinae	Acrididae
Oedaleus flavus somaliensis	Oedipodinae	Acrididae
Oedaleus instillatus	Oedipodinae	Acrididae
Oedaleus sengalensis	Oedipodinae	Acrididae
Ornithacris cyanea	Cyrtacanthacridinae	Acrididae
Orthochtha dasycnemis	Acridinae	Acrididae
Oxyeous apertus	Phaneropterinae	Tettigoniidae
Paracinema tricolor	Oedipodinae	Acrididae
Parasphena meruensis		Pyrgomorphidae
Parasphena pulchripes		Pyrgomorphidae
Parepistaurus deses	Coptacrinae	Acrididae
Parepistaurus lindneri	Coptacrinae	Acrididae
Parga cyanoptera	Acridinae	Acrididae
Peronura clavigera	Phaneropterinae	Tettigoniidae
Phaeocatantops concolor	Catantopinae	Acrididae
Phaeocatantops decoratus	Catantopinae	Acrididae
Phaneroptera sparsa	Phaneropterinae	Tettigoniidae
Phlesirtes merumontanus	Conocephalinae	Tettigoniidae
Phymateus aegrotus		Pyrgomorphidae
Phymateus viripides		Pyrgomorphidae
Phymeurus granulatus	Euryphyminae	Acrididae
Phyteumas purpurascens		Pyrgomorphidae
Plagiotriptus hippiscus		Thercleidae
Plangia multimaculata	Phaneropterinae	Tettigoniidae
Plangia satiscaerulea	Phaneropterinae	Tettigoniidae
Pnorisa squalus	Gomphocerinae	Acrididae
Pycnodictya galinieri	Oedipodinae	Acrididae
Pyrgomorpha conica		Pyrgomorphidae
Pyrgomorphella albini		Pyrgomorphidae
Rhaphotittha levis	Gomphocerinae	Acrididae
Rhaphotittha subtilis	Gomphocerinae	Acrididae
Ruspolia differens	Conocephalinae	Tettigoniidae
Ruspolia exigua	Conocephalinae	Tettigoniidae
Spalacomimus stettinensis	Hetrodinae	Tettigoniidae
Spalacominus talpa	Hetrodinae	Tettigoniidae
Spalacominus verruciferus	Hetrodinae	Tettigoniidae
Sphingonotus turkanae	Oedipodinae	Acrididae
Stenohippus maculifemur	Gomphocerinae	Acrididae
Stenohippus trochilus	Gomphocerinae	Acrididae
Stenohippus xanthus	Gomphocerinae	Acrididae
Taphronota calliparea		Pyrgomorphidae
Taramassus cunctator	Eyprepocnemidinae	Acrididae
Tenerasphaga meruensis	Phaneropterinae	Tettigoniidae
Truxalis conspurcata somalia	Gomphocerinae	Acrididae
Terpnistria zebrata	Phaneropterinae	Tettigoniidae
Trichocatantops villosus	Catantopinae	Acrididae
Trilophidia conturbata	Oedipodinae	Acrididae
Tristria pallida	Tropidopolinae	Acrididae
Tropidonotacris grandis	Phaneropterinae	Tettigoniidae
Truxalis burtti	Gomphocerinae	Acrididae
Tylopsis dispar	Phaneropterinae	Tettigoniidae
Tylopsis rubrescens	Phaneropterinae	Tettigoniidae
Uganda kilimandjarica	Acridinae	Acrididae
Usambilla olivacea		Lentulidae
Usambilla turgidicrus		Lentulidae
Zabalius ophthalmicus	Pseudophyllinae	Tettigoniidae
Zonocerus elegans		Pyrgomorphidae

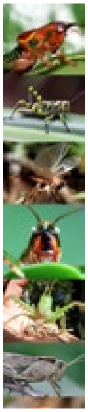


Fig. 9 (above). Claudia Hemp and **Fig. 10.** (left) field assistant Erick Materu catching bushcrickets in the canopy.

Outreach activities of the KiLi Project

The KiLi Project built up two scientific gardens in order to be able to perform experiments of biomass growth and resilience of trees species planted in different elevations (SP4, Andreas Hemp, Markus Fischer & PhD students Neduvoto Mollel, Gemma Rutten, Andreas Enßlin & Marion Renner, see results under respective Subproject 4). When the experiments were finished the gardens were used to grow indigenous tree species of Tanzania. Together with the NGO TanzMont with its headquarters in Kidia, Old Moshi, more than 2000 young trees were reared from seeds and planted in deforested areas along the the river Msaranga and in an savanna area.

Together with TanzMont a poster compiled was distributed locally and among some authorities in Moshi for display (Fig. 2).

Fig. 1. Saplings of endangered Tanzanian tree species, e.g. the species *Oxystigma msoo* in the newly built tree nursery Kidia November 2017. *O. msoo* is recorded from today deforested localities in Kenya and the Kilimanjaro area. In the latter only 60 mature specimens were counted in 2017 (4 in Kahe Forest – a forest almost destroyed today), the remaining grow in the Rau Forest near Moshi.

NGO TanzMont

Kidia, Old Moshi

Aims of the NGO TanzMont

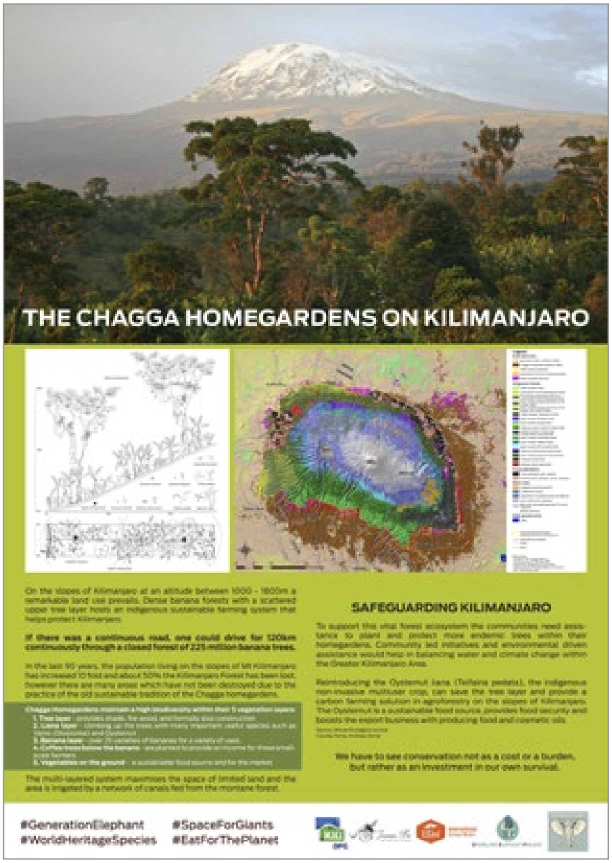
The NGO TanzMont propagates to plant indigenous trees and to restore deforested areas and admonishing to obey to Tanzanian laws regarding riverine vegetation

Fig. 2. TanzMont poster advising planting indigenous trees and not to cut down riverine forest or misuse it for agriculture since it has negative consequences for the water balance and the biodiversity in the area.

Highlighting the Chagga homegardens and to advertise to plant Oysternut

The Chagga homegardens maintain a high biodiversity, and they are an old and very sustainable way of land-use that meets several different demands. Beside crop production, the sparse tree layer provides people with firewood, fodder and timber. But the high demand of wood, low coffee prizes on the world market and the introduction of coffee varieties that are sun-tolerant endanger this effective system. In order to reduce the pressure on the forest, it is necessary, to support the tree planting in the Chagga homegardens with their unique agroforestry system. It can be estimated that a homegarden supplies ¼ to ⅓ of the fuelwood requirements of a family. As the banana belt is nearly as extensive as the forest belt, this will of course have major effects in terms of forest protection and the water balance.

The Chagga homegardens maintain a high biodiversity with over 500 species including 400 not cultivated plants. This is about three quarter of the species occurring in the ruderal vegetation formation (i.e. vegetation on road sides, waste places and fallow arable land) on Kilimanjaro. With over 700 species this formation holds rank three in respect of species richness after the forests and grasslands on Mt Kilimanjaro. Most areas of the submontane and lower montane coffee-banana belt resemble woodland with a dense undergrowth of bananas. Beside a wealth of plant species a study on the Orthoptera (grasshoppers, bushcrickets & crickets) showed that the Chagga homegardens provide habitat to more than half of the endemics occurring from the colline to the afro-alpine zone of Mt Kilimanjaro. Therefore, the KiLi Project together with other organisations e.g. Slow Food Tanzania promote that the Chagga homegardens should be protected and supported in its structure and extend. In parallel more intensive planting of the Oysternut or "Kweme" will create income to the local farmers, provide a very valuable indigenous and healthy source of food and will help to maintain the so important tree layer in the Chagga homegardens since the Oysternut needs large and strong trees (mainly *Albizzia schimperinana*) to grow on.



THE CHAGGA HOMEGARDENS ON KILIMANJARO

On the slopes of Kilimanjaro at an altitude between 1000 – 1800m a remarkable land use prevails. Dense banana forests with a scattered upper tree layer hosts an indigenous sustainable farming system that helps protect Kilimanjaro.

If there was a continuous road, one could drive for 120km continuously through a closed forest of 225 million banana trees.

In the last 90 years, the population living on the slopes of Mt Kilimanjaro has increased 10 fold and about 50% the Kilimanjaro Forest has been lost, however there are many areas which have not been destroyed due to the practice of the old sustainable tradition of the Chagga homegardens.

Chagga homegardens maintain a high biodiversity within their 5 vegetation layers:

1. **Tree layer** – provides shade, fire wood, and formally also construction
2. **Liana layer** – climbing up the trees with many important useful species such as Vanilla (Oysternut) and Dioscorea
3. **Banana layer** – over 75 varieties of bananas for a variety of uses
4. **Coffee trees below the banana** – are planted to provide an income for these small-scale farmers
5. **Vegetables on the ground** – a sustainable food source and for the market

The multi-layered system maximises the space of limited land and the area is irrigated by a network of canals fed from the montane forest.

SAFEGUARDING KILIMANJARO

To support this vital forest ecosystem the communities need assistance to plant and protect more endemic trees within their homegardens. Community led initiatives and environmental driven assistance would help in balancing water and climate change within the Greater Kilimanjaro Area.

Reintroducing the Oysternut liana (Telfairia pedata), the indigenous non-invasive multiuser crop, can save the tree layer and provide a carbon farming solution in agroforestry on the slopes of Kilimanjaro. The Oysternut is a sustainable food source, provides food security and boosts the export business with producing food and cosmetic oils.

We have to see conservation not as a cost or a burden, but rather as an investment in our own survival.

#GenerationElephant #SpaceForGiants
#WorldHeritageSpecies #EatForThePlanet

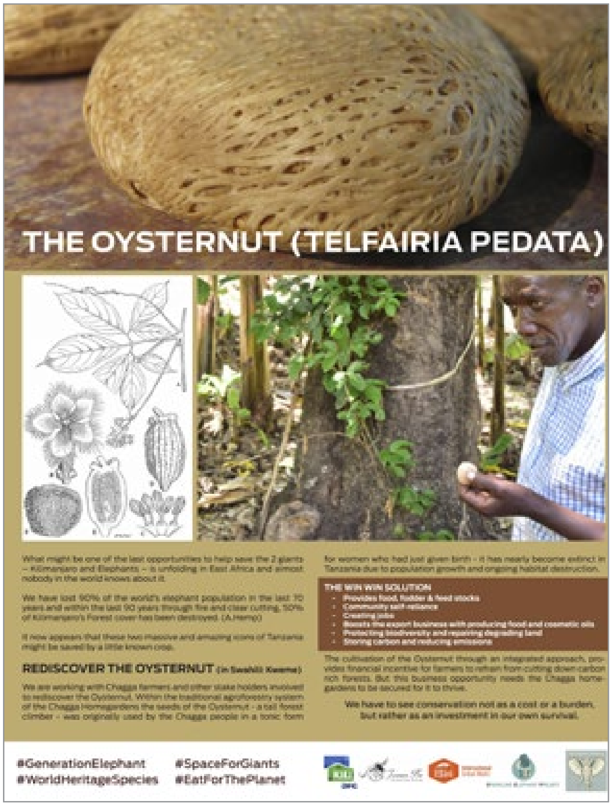
Fig. 3. Poster with information on the Chagga homegardens on Mt Kilimanjaro.

For more information see:

Hemp C (2005). The Chagga homegardens – relict areas for endemic Saltatoria Species (Insecta: Orthoptera) on Mt Kilimanjaro. Biological Conservation 125: 203-210.

Hemp A (2006). The banana forests of Kilimanjaro. Biodiversity and conservation of the agroforestry system of the Chagga homegardens. Biodiversity and Conservation 15(4): 1193-1217.

Hemp C, Hemp A (2008). The Chagga homegardens on Kilimanjaro. IHDP Update. Magazine of the International Human Dimensions Programme on Global Environmental Change: 12-17.



THE OYSTERNUT (TELFAIRIA PEDATA)

What might be one of the last opportunities to help save the 2 giants – Kilimanjaro and Elephants – is unfolding in East Africa and almost nobody in the world knows about it.

We have lost 90% of the world's elephant population in the last 70 years and within the last 90 years through fire and clear cutting, 50% of Kilimanjaro's Forest cover has been destroyed. (A.Hemp)

It now appears that these two massive and amazing icons of Tanzania might be saved by a little known crop.

REDISCOVER THE OYSTERNUT (in Swahili Kweme)

We are working with Chagga farmers and other stake holders involved to rediscover the Oysternut. Within the traditional agroforestry system of the Chagga Homegardens the seeds of the Oysternut - a tall forest climber - was originally used by the Chagga people in a tonic form for women who had just given birth - it has nearly become extinct in Tanzania due to population growth and ongoing habitat destruction.

THE WIN WIN SOLUTION
- Provides food, fodder & feed stocks
- Community self-reliance
- Creating jobs
- Boosts the export business with producing food and cosmetic oils
- Protecting biodiversity and repairing degrading land
- Storing carbon and reducing emissions

The cultivation of the Oysternut through an integrated approach, provides financial incentive for farmers to refrain from cutting down carbon rich forests. But this business opportunity needs the Chagga homegardens to be secured for it to thrive.

We have to see conservation not as a cost or a burden, but rather as an investment in our own survival.

#GenerationElephant #SpaceForGiants
#WorldHeritageSpecies #EatForThePlanet

Fig. 4. Oysternut poster presented at numerous events.

Fig. 5. "Slow Food" meeting, Moshi November 2017 discussing the protection of the Chagga homegardens with local and several other East Africa organizations and the propagation of the Oysternut.

Fig. 6. Presentations in event tent at Kili Fair in Moshi June 2017. The talks gave information about the Chagga homegardens, the Oysternut as valuable food, the Kitenden corridor as essential area for wildlife migration in the Kilimanjaro area, and the declining numbers of giraffe and lions in Africa.

further Literature:

Hemp A, Hemp C, JC Winter (2009). 14. Environment and Worldview: The Chagga homegardens: 235-303. In: T.A.R. Clack (ed.): Culture, History and Identity: Landscapes of Inhabitation in the Mount Kilimanjaro Area, Tanzania Essays in honour of Paramount Chief Thomas Lenana Mlanga Marealle II (1915-2007). BAR International Series 1966. Archaeopress, Oxford.

Hemp A, Hemp C (2011). In: Liniger, H.P., R. Mekdaschi Studer, C. Hauert and M. Gurtner (Eds). Sustainable Land Management in Practice – Guidelines and Best Practices for sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO). Case Study: Chagga homegardens – Tanzania: 132-133.

Fig. 7. The touristic organization "Fairtrek Jicho Germany / Tanzania" is interested in more education in environmental matters for their guides and porters and would be interested in a programm with the KiLi Project sharing experience and knowledge.
For more information see: **www.fairtrek-jicho.de,** www.fairtrek-jicho-tanzania.com.

Figs. 8–10 (clockwise from left below). Students of the Catholic Academic Exchange Service (KAAD) visiting the scientific station Nkweseko.
Presentation of the KiLi Project at International School of Moshi, Diploma class.
Visit of the E.T.A. Hoffmann Gymnasium Bamberg in November 2017. This school has visited the scientific stations Nkweseko and Kidia for the fourth year.

Fig. 11. The Scientific Station Nkweseko is a member of the **Organization of Biological Field Stations** (OBFS) with the majority of field stations in the United States of America.

Figs 12–14 (below). The Research Stations of **Mpala**, Kenya (Laikipia) and the **Scientific Station Nkweseko** agreed to colaborate. A first project was started in May 2017 comparing Orthoptera communities in different treated savanna grass- and woodlands in Mpala.

MPALA

THE MPALA RESEARCH CENTRE &
THE MPALA WILDLIFE FOUNDATION

Facilities

Research

Donate Now

7qj4

AfroMont

Research Network on Global Change in African Mountains

AfroMont-Mt Kilimanjaro Mountain Research Meeting 22–26 February 2017

Sessions for the research meeting were:

- Kilimanjaro ecosystems under global change: Linking biodiversity, biotic interactions and biogeochemical ecosystem processes
- Tracking change in African mountain ecosystems
- Foreign land acquisitions and new land-uses in African mountains
- Making the case for Sustainable Mountain Development
- Mountain governance – protected areas, Biospheres and World Heritages Sites – are they effective or what else is needed

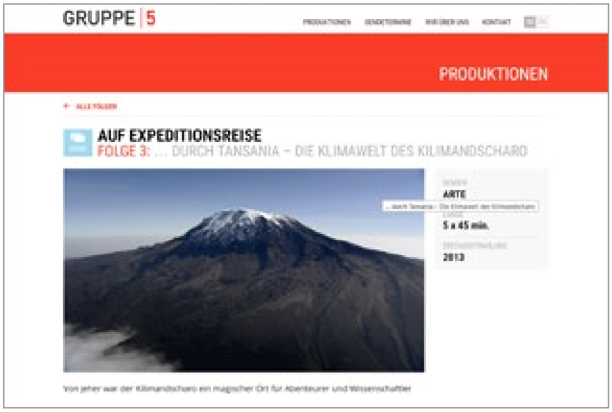
For more information and to download the extended abstracts of the meeting please visit: http://mri.scnatweb.ch/en/mri-africa-news/afromont-mt-kilimanjaro-research-group-meeting

Figs. 1–5 (above to below). Kippi Warioba, the district commissioner of Moshi, opening the meeting. Sessions at the Uhuru Hostel in Moshi 2nd (middle right), excursion explaining the Chagga homegardens (3rd middle right) and to Lake Chala (below left). Below right.: Participants of the AfroMont meeting held in Moshi.

The KiLi Project and the Media

compiled by Claudia Hemp

The unique research design of the KiLi Project, the general set-up and results of our research on the mountain attracted attention of the media. Thus, in July 2013 our PhD student Ephraim Mwangomo advised a film team of **National Geographic** preparing a documentation on the mountain and in October 2013 a second film team from **ARTE** focused on our research unit. A documentary was prepared in the French and German language with the Title "Auf Expeditionsreise durch Tansania: Die Klimawelt des Kilimanjaro". This 45 min documentary can be watched at:
https://www.youtube.com/watch?v=kgRrJKdY8Jw.
The discovery of the tallest trees of Africa attracted world-wide interest and the feedback was overwhelming. Several videos clips e.g. from **Deutsche Welle** or **AZAM News** (TWO) were broadcasted on various senders, especially in Tanzania:
Deutsche Welle: http://www.dw.com/en/africas-tallest-tree-under-threat/av-37978836
AZAM: https://www.youtube.com/watch?v=jfAYmwYW_Ls
A large Balloon Bushcricket in the Udzungwa Mountains of Tanzania also received attention:
https://www.youtube.com/watch?v=1XT7MuL7V_g



AUF EXPEDITIONSREISE
FOLGE 3: … DURCH TANSANIA – DIE KLIMAWELT DES KILIMANDSCHARO

Von jeher war der Kilimandscharo ein magischer Ort für Abenteurer und Wissenschaftler

Fig. 2. Advertisement of ARTE for documentation on KiLi Project research.

Africa's tallest tree under threat

Fig. 3. Deutsche Welle website where the video on tallest trees of Africa may be watched.

Fig. 1. ARTE filmteam shooting on the Scientific Station Nkweseko.

Fig. 4. Video clip on rare whistling bushcricket.

Tanzanian Counterparts of the KiLi Project

Dr. Victor Kakengi, Tanzania Wildlife Research Institute (TAWIRI), kakengi1@yahoo.com.

Dr. Julius Keyyu, Tanzania Wildlife Research Institute (TAWIRI), julius.keyyu@tawiri.or.tz.

Prof. Pius Z. Yanda, Director Centre for Climate Change Studies (CCCS) University of Dar es Salaam P. O. Box 33453 Dar es Salaam – Tanzania Tel: +255-22-2410 707 Mobile: +255 754 265 580 Fax: +255-22-2410 473 Website: www.cccs.udsm.ac.tz; e-mail: pyanda@gmail.com, yanda@ira.udsm.ac.tz

Mr. Nyamakumbati Mafuru, Head of Kilimanjaro National Park, Kilimanjaro National Park, P.O Box 3134, Arusha, Tanzania
Ephraim Anosisye Mwangomo, Ecologist of the Kilimanjaro National Park, Kilimanjaro National Park, P.O Box 3134, Arusha, Tanzania

Mr. Erasmus Lufungulo, Head of Kilimanjaro National Park, Kilimanjaro National Park, P.O Box 3134, Arusha, Tanzania

Mrs Betrita Loibooki, Head of Kilimanjaro National Park, Kilimanjaro National Park, P.O Box 3134, Arusha, Tanzania

Prof. Kim M. Howell, Dept. of Zoology & Wildlife Conservation, University of Dar es Salaam, Box 35064, Dar es Salaam, Tanzania, Tel.: +255(22) 2410462, mobile: +255 754 580 456, e-mail: kmhowell@udsm.ac.tz

Dr. Paul Msemwa, National Museum of Tanzania, Shaaban Robert Street, P.O. Box 511, Dar es Salaam, Tanzania, http://www.houseofculture.or.tz/; E-mail: director@houseofculture.or.tz

Dr. Hassan Shombe, Dept. of Wildlife Management, Sokoine Universiy of Agriculture, Morogoro, Tanzania, Phone: +255753767635, E-mail: hassanshombe@yahoo.co.uk.

Prof. Dr. R.P.C Temu, Sokoine University of Agriculture, Dept of Forest Biology, Box 3010 Morogoro, Tanzania, Email: rpctemu@suanet.ac.tz

Prof. Pantaleo K. T. Munishi, Sokoine University of Agriculture, P.O. Box 3010, Chuo Kikuu, Morogoro, Tanzania, Phone: direct: +255 2604944; general: +255-023-2 603511, Fax: +255 23 2604652, http://www.suanet.ac.tz/forestry/Munishi.htm; E-mail: pmunishi2001@yahoo.com and dvc@suanet.ac.tz

Prof. Dr. Salim M.S. Maliondo, Sokoine University of Agriculture, Dep. of Forest Biology, Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, P.O. Box 3010, Morogoro, Tanzania, Phone: +255 757 996979, Mobile +255 786 296613, e-mail: maliondo@giant.suanet.ac.tz; smaliondo@yahoo.co.uk

Alfred Chitiki, Forest scientist, Sokoine University of Agriculture, Department of Forest Biology, Morogoro, Tanzania, Tel +255786713089, alchitiki@yahoo.com; chitiki@suanet.ac.tz

Mrs Epiphania Kimaro, Director General TPRI, Arusha; kimaro_epi@yahoo.com

Dr. Margaret Mollel, Principal Research Scientist National Plant Genetic Resources Centre P.O Box 3024 Arusha, Tanzania Tel: +255 27 250 9674 Fax: +255 27 250 9674 Mobile:+255 787 935261, e-mail: mjk_mollel@yahoo.com

Dr. Neduvoto Piniel Mollel, Curator National Herbarium TPRI, Arusha, P.O. Box 3024. nmollel@tpri.or.tz

Dr. E.E.K. Mjemah, Training officer, Tropical Pesticides Research Institute, P.O. Box 3024, Arusha, Tanzania, Tel 027 250 881316 Fax Tel 027 250 881317, email tpri@ habari.co.tz

Freddy S. Manongi, Deputy Principal Academic, College of African Wildlife Management, Mweka, P.O.Box 3031 Moshi, Tanzania, Phone +255787679920, +255272756422, +255272756414, E-mail: fsmanongi@yahoo.com

Dr. H. Nkotagu, University of Dar es Salaam, Department of Geology, hudson@udsm.ac.tz

Dr. Hamadi Dulle, Lecturer and Head of Department, College of African Wildlife Management, Mweka. dullehamadi@yahoo.com

Fig. 1. (above left). KiLi annual meeting 2012 with Dr J. Keyyu and Dr V. Kakengi (both Tawiri and counterparts of the KiLi Project) and Claudia Hemp, KiLi coordinator. **Fig. 2** (above right). Visit of Dr V. Kakengi to Germany in June 2015 visiting and giving talks at the Universities of Bayreuth, Würzburg and Frankfurt. On this photo Victor is shown the beautiful landscape of "Frankonian Switzerland". **Fig. 3** (below left). Invitation of the Director General of Tawiri, Dr S. Mduma and Dr V. Kakengi to the annual meeting of the Society of Tropical Ecology at Zürich, Switzerland in April 2016. An excursion together with Dr Neduvoto Mollel (TPRI) – PhD student at that time, led the guests to the Swiss Alps. **Fig. 4** (below right). Chief Park Warden of the Kilimanjaro National Park (KINAPA) Betrita Loibooki and Andreas Hemp in March 2016.

Fig. 5–8. Annual meeting of the KiLi-Group in January 2018 in Frankfurt, Germany. **Fig. 5** (above left) from left to right: Imani Kikoti (Senior Park Ecologist KINAPA and former master student), Dora Aloyce, Senior Park Warden for Tourism, Tarangire National Park, Fortunata Msoffe, Chief Park Warden – GIS unit, TANAPA HQ and PostDoc, Betrita Loibooki, Chief Park Warden KINAPA, Victor Kakengi, research officer TAWIRI and counterpart, Robert Modest, Sokoine University and PostDoc, Beatrice Mmary, assistant coordinator KiLi Project, Katrin Böhning-Gaese, speaker KiLi Project and Andreas Hemp, Bayreuth University and leader KiLi Project. **Fig. 6** (above right): Katrin Böhning-Gaese, Andreas Hemp, Allan Kijazi (Director General TANAPA) and Markus Fischer, University of Bern and leader KiLi Project at Bik-Frankfurt. **Fig. 7** (below left): Allan Kijazi and Victor Kakengi. **Fig. 8** (below right): Visiting the Marksburg above the River Rhine with the group.

Conclusions & Outlook

by Claudia & Andreas Hemp & Markus Fischer

In the frame of the KiLi Project more than 60 Master and PhD students were educated among them 16 Tanzanians. All students worked interdisciplinary on the same research plots successively up-loading their data into a common data base accessible to all members and the counterparts of the project during two phases from 2010 to 2016. The results of our research were published in more than 100 scientific papers, some of them in high-ranking journals attracting world-wide interest.

All studies in all investigated habitat systems from the savanna to the montane forest and above showed that ecosystem services suffered with too intensive land-use. Although highly influenced by anthropogenic use the Chagga homegardens proved to be astonishingly sustainable and resilient with a high biodiversity since the Chagga people use the fertile volcanic soil in a multi-layered system. Tree species from the former forest remained providing shade to crops planted underneath. Many indigenous and partly to Kilimanjaro endemic plant and animal species still find habitat in these homegardens while commercial coffee plantations in same elevations – especially when intensively treated with herbi- and pesticides – were extraordinarily poor in biodiversity as were maize monocultures in savanna habitats compared to semi-natural savanna grass and woodlands. Our results also clearly showed that soils suffered badly from too much use of chemical agents loosing their function to retain water and nutrients. Such systems very likely will be most negatively affected by ongoing climate change while land-use systems comparatively rich in biodiversity will be more resilient against rising temperatures and less precipitation.

Kilimanjaro – the highest freestanding mountain on earth with an unique climatic gradient and its wealth of different habitats from natural to highly anthropogenic transformed areas hereby was the perfect study site representing a rapidly changing world in the tropics.

The KiLi Project must be understood as a first approach to address the important research topic of global change while many thrilling questions are yet left to be investigated in the future. Kilimanjaro with its unique elevational gradient on one hand and its array of different habitats ranging from pristine nature to 100% anthropogenic transformed areas was and will be the ideal laboratory to address key questions for humans in a changing world.

Acknowledgements

We would like to express sincere thanks to all the land owners that patiently allowed us to study their properties, granting access during day and nighttime for the different students to work on their scientific projects. Our thanks also go to Tanzanian authorities showing interest in our projects and permitting research in granting permits. Our special thanks hereby go to **Dr. Hassan Mshinda**, Director General of the Commission of Science and Technology and **Mr. Mashuhuri Mushi** (COSTECH), the Chief Park Wardens of Kilimanjaro National Park (**Mr. Mafuru, Mr. Lufungulo** and **Mrs Betrita Loibooki**) supporting our team in the Kilimanjaro National Park. Our thanks also to the Tanzania Wildlife Institute (TAWIRI) permitting research. Special thanks to the Director General of Tawiri, **Dr. Simon Mduma** for his continuous interest and special support. Further our gratitude goes to our counterparts **Dr. Julius Keyyu** and **Dr. Victor Kakengi** (both TAWIRI) always supporting us as well and sharing ideas with us. We also want to mention **Mr. Inyasi Lejora** of the Tanzania National Parks having always an open ear and supporting us with the many questions and queries we had over time.

Last but not least we want to mention our whole team, master and PhD Students, our PostDocs and Professors being the motor of this research group and whose achievement it was that the project successfully ran for more than 8 years with enormous scientific output contributing to the key questions of **"Kilimanjaro ecosystems under global change: Linking biodiversity, biotic interactions and biogeochemical ecosystem processes".**

Acknowledgements from the KiLi Staff

by Beatrice Mmary

The staff of the KiLi Project thanks God for the blessing he brought to us to have employment with the KiLi Project, many of us since 2010. Our sincere thanks to the German Research Foundation making this project possible.

We want to thank Drs Andreas and Claudia Hemp that they initiated this project. Without it our lives would have been much different and harder. So we hope with the help of the Almighty God we will continue with another project financed by the German Research Foundation.

We want to state the following: 1. Because of the German Research Foundation we all got wonderful jobs. Our kids can be educated and have a good future ahead of them. We pray to God that we will be further employed to secure our families.

2. Many of the employed staff got a good education because they learned so many things and improved their skills in the English language while working for the various students of the KiLi Project. We are very grateful for the opportunities we got. Many of us got knowledge about environmental matters, learning about tree and animal species together with their names and their importance for nature.

3. The findings of the KiLi Research group brought international researchers to our area and some of the findings drew the attention of the whole world to our area. The discovery of the tallest trees is now important for tourism in the areas of Old Moshi and Mbokomu, many more tourists have come since.

Finally, again: we are very grateful for the funding of the German Research Foundation securing our lives, and we pledge that the research can be continued in our wonderful country Tanzania.

Fig. 1. Part of the staff during the AFROMONT congress in February 2017. From left to right: Alexander Mmary (driver), Judica Malisa (Matron Kidia), Julieth Mshida (scientific garden helper) and Beatrice Mmary (assistant coordinator).

List of authors

Adhikari, Hari, Earth Change Observation Laboratory / Department of Geosciences and Geography, P.O. Box 68, FIN-00014 University of Helsinki, Finland

Appelhans, Tim, Philipps-University Marburg, Ecoinformatics, Deutschhausstraße 12, 35032 Marburg, Germany

Becker, Joscha, Georg August University of Göttingen, Soil Science of Temperate Ecosystems, Büsgenweg 2, 37077 Göttingen, Germany

Behling, Hermann, Georg-August University Göttingen, Department of Palynology and Climate Dynamics, Untere Karspüle 2, 37073 Göttingen, Germany

Berauer, Bernd, University of Bayreuth, Disturbance Ecology, Universitätsstrasse 30, 95440 Bayreuth, Germany

Bogner, Christina, University of Bayreuth, Ecological Modelling, Dr.-Hans-Frisch-Straße 1–3, D 95448 Bayreuth, Germany

Bohn, Friedrich, Karlsruhe Institute of Technology, IMK – IFU, Institute of Meteorology and Climate Research – Atmospheric Environmental Research, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany

Böhning-Gaese, Katrin, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Brandl, Roland, Animal Ecology, Department of Ecology, Faculty of Biology, Philipps-Universität Marburg, Karl-von-Frisch-Strasse 8, 35032 Marburg, Germany

Buchroithner, Manfred, Technical University of Dresden, Institute of Cartography, Helmholtzstraße 10, 01069 Dresden, Germany

Claßen, Alice, University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter – Am Hubland, 97074 Würzburg, Germany

Detsch, Florian, Philipps-University Marburg, Ecoinformatics, Deutschhausstraße 12, 35032 Marburg, Germany

Dippold, Michaela, Georg August University of Göttingen, Department of Biogeochemistry of Agroecosystems, Büsgenweg 2, 37077 Göttingen, Germany

Dulle, Hamadi, College of African Wildlife Management Mweka, P. O. Box 3031, Moshi, Tanzania

Enghoff, Henrik, Natural History Museum of Denmark, University of Copenhagen, Universitetsparken 15, DK-2100 Koebenhavn OE, Danmark

Enßlin, Andreas, Markus Fischer, University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Ferger, Stefan, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Fischer, Markus, University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Frederiksen, Sara, Natural History Museum of Denmark, University of Copenhagen, Universitetsparken 15, DK-2100 Koebenhavn OE, Danmark

Gebert, Friederike, University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter – Am Hubland, 97074 Würzburg, Germany

Gerschlauer, Friederike, Karlsruhe Institute of Technology, IMK – IFU, Institute of Meteorology and Climate Research – Atmospheric Environmental Research, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany

Gunina, Anna, University of Kassel, Department of Environmental Chemistry, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

Gütlein, Adrian, Karlsruhe Institute of Technology, IMK – IFU, Institute of Meteorology and Climate Research – Atmospheric Environmental Research, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany

Hardy, Douglas R., University of Massachusetts Amherst, Department of Geosciences, Amherst Center, United States

Helbig Bohnitz, Maria, University of Ulm, Institute of Evolutionary Ecology, and Conservation Genomics, Albert Einstein Allee 11, D 89069 Ulm, Germany

Hemp, Andreas, University of Bayreuth, Plant Systematics, Universitätsstr. 30, 95447 Bayreuth, Germany

Hemp, Claudia, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Henninger, Hans, Karlsruhe Institute of Technology, IMK – IFU, Institute of Meteorology and Climate Research – Atmospheric Environmental Research, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany

Hertel, Dietrich, Georg August University of Göttingen, Ecology and Ecosystem Research, Grisebachstr. 1, D-37077 Goettingen, Germany

Howell, Kim, University of Dar es Salaam, Dept. of Zoology and Wildlife Conservation, P.O. Box 35091, Dar es Salaam, Tanzania (professor emeritus)

Hurskainen, Pekka, Earth Change Observation Laboratory / Department of Geosciences and Geography, P.O. Box 68, FIN-00014 University of Helsinki, Finland

Huth, Andreas, Helmholtz Centre for Environmental Research – UFZ, Department of Ecological Modelling, Permoserstr. 15, 04318 Leipzig, Germany

Huwe, Bernd, University of Bayreuth, Department of Soil Physics, Universitätsstr. 30, 95447 Bayreuth, Germany

Kaasalainen, Ulla, Finnish Museum of Natural History, P.O.Box 7, 00014 University of Helsinki, Finland

Kakengi, Victor, Alexander, Tanzania Wildlfe Research Institute, P.O. Box 661, Arusha, Tanzania

Kalko (†), Elisabeth, University of Ulm, Institute of Evolutionary Ecology and Conservation Genomics, Albert Einstein Allee 11, D 89069 Ulm, Germany

Kiese, Ralf, Karlsruhe Institute of Technology, IMK – IFU, Institute of Meteorology and Climate Research – Atmospheric Environmental Research, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany

Kikoti, Imani, Kilimanjaro National Park, P.O.Box 96, Marangu, Tanzania

Kimaro, Jerome, University of Bayreuth, Department of Soil Physics, Universitätsstr. 30, 95447 Bayreuth, Germany and Tanzania Wildlfe Research Institute, P.O. Box 661, Arusha, Tanzania

Kleyer, Michael, University of Oldenburg, Department of Biology, Earth and Environmental Sciences, 26111 Oldenburg, Germany

Kühnel, Anna, University of Bayreuth, Department of Soil Physics, Universitätsstr. 30, 95447 Bayreuth, Germany

Kuzyakov, Yakov, Georg August University of Göttingen, Soil Science of Temperate Ecosystems, Büsgenweg 2, 37077 Göttingen, Germany

Leuschner, Christoph, Georg August University of Göttingen Ecology and Ecosystem Research, Grisebachstr. 1, D-37077 Goettingen, Germany

Luther-Medoch, Bente, Machare/Uru Estates, P.O.Box 1088, Moshi, Tanzania

Mmary, Beatrice, Stephen, Lutheran Parish Kidia, P.O. Box 317, Moshi, Tanzania

Mnyonga, James, Sokoine University of Agriculture, P.O. Box 3000, Chuo Kikuu, Morogoro, Tanzania

Molina-Venegas, Rafael, University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Mollel, Neduvotu, Piniel, Tropical Pesticides Research Institute, Herbarium, P.O. Box 3024, Arusha. Tanzania.

Montade, Vincent, Georg-August University Göttingen, Department of Palynology and Climate Dynamics, Untere Karspüle 2, 37073 Göttingen, Germany

Mushi, Hawa, Landscape Ecology Group, Institute of Biology and Environmental Sciences, University of Oldenburg, 26111 Oldenburg, Germany

Mwangomo, Ephraim, Tanzania National Parks, P. O. Box 3134, ARUSHA, Tanzania

Nauß, Thomas, Philipps-University Marburg, Ecoinformatics, Deutschhausstraße 12, 35032 Marburg, Germany

Ndossi, Emanuel, Georg August University of Göttingen, Soil Science of Temperate Ecosystems, Büsgenweg 2, 37077 Göttingen, Germany

Ngereza, Christine, Fishaa, Department of Collection Management, National Museum of Tanzania, P.O. Box 511, Dar es Salaam, Tanzania

Oleson, Ethan, Technical University of Dresden, Institute of Cartography, Helmholtzstraße 10, 01069 Dresden, Germany

Otte, Insa, Philipps-University Marburg, Ecoinformatics, Deutschhausstraße 12, 35032 Marburg, Germany **Pabst, Holger**, Georg August University of Göttingen, Soil Science of Temperate Ecosystems, Büsgenweg 2, 37077 Göttingen, Germany

Peters, Marcell, University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter – Am Hubland, 97074 Würzburg, Germany

Pommer, Ulf, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Remmele, Sabine, University of Hohenheim, General Botany, Forest Ecology and Remote Sensing Group, Garbenstrasse 30, 70599 Stuttgart, Germany

Renner, Marion, University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Rikkinen, Jouko, Finnish Museum of Natural History, P.O.Box 7, 00014 University of Helsinki, Finland

Röder, Juliane, Animal Ecology, Department of Ecology, Faculty of Biology, Philipps-Universität Marburg, Karl-von-Frisch-Strasse 8, 35032 Marburg, Germany

Rutten, Gemma,University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland

Scharsich, Valeska, University of Bayreuth, Department of Soil Physics, Universitätsstr. 30, 95447 Bayreuth, Germany

Schellenberger Costa, David, Friedrich Schiller University Jena, Institute of Ecology and Evolution, Dornburger Strasse 159, 07743 Jena, Germany

Schleuning, Matthias, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Scholl, Martha, Water Resources, U.S. Geological Survey, National Research Program Reston, VA, USA

Schüler, Lisa, Georg-August University Göttingen, Department of Palynology and Climate Dynamics, Untere Karspüle 2, 37073 Göttingen, Germany

Sierra Cornejo, Natalia, Georg August University of Göttingen, Ecology and Ecosystem Research, Grisebachstr. 1, D-37077 Goettingen, Germany

Steffan-Dewenter, Ingolf, University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter – Am Hubland, 97074 Würzburg, Germany

Tschapka, Marco, University of Ulm, Institute of Evolutionary Ecology, and Conservation Genomics, Albert Einstein Allee 11, D 89069 Ulm, Germany

Vogeler, Anna, University of Ulm, Institute of Evolutionary Ecology, and Conservation Genomics, Albert Einstein Allee 11, D 89069 Ulm, Germany

Vollstädt, Maximilian, Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt (Main), Germany

Yanda, Pius, Z., Institute of Resource Assessment, University of Dar Es Salaam, P.O. BOX 35097, Dar Es Salaam, Tanzania

Zancolli, Giulia, Molecular Ecology and Fisheries Genetics Lab, School of Biological Sciences, Bangor University, Environment Centre Wales, Bangor LL57 2UW, UK

Zhang, Jie, University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter – Am Hubland, 97074 Würzburg, Germany

Zimmermann, Reiner, University of Hohenheim, General Botany, Forest Ecology and Remote Sensing Group, Garbenstrasse 30, 70599 Stuttgart, Germany

List of publications by the KiLi Project 2010–2018

Hemp, C., Voje, K., Heller, K.-G., Warchałowska-Sliwa, E., Hemp, A. (2010) A new genus in African Acrometopini (Tettigoniidae: Phaneropterinae) based on morphology, chromosomes, acoustics, distribution and molecular data and the description of a new species. Zoological Journal of the Linnean Society 158(1): 66–82.

Hemp, C. (2010) Cloud forests in East Africa as evolutionary motors for speciation processes of flightless Saltatoria species. In: Mountains in the Mist: Science for Conservation and Management of Tropical Montane Cloud Forests, eds. L.A. Bruijnzeel, F.N. Scatena, and L.S. Hamilton. University of Hawaii Press, Honolulu. Chapter 18: 192–196.

Hemp, C., Heller K.-G., Kehl S., Warchałowska-Sliwa E., Wägele J.W., Hemp A. (2010) The *Phlesirtes* complex (Orthoptera, Tettigoniidae, Conocephalinae, Conocephalini) reviewed: integrating morphological, molecular, chromosomal, and bioacoustic data. Systematic Entomology 35: 554–580.

Hemp, C., Heller K.-G., Warchałowska-Sliwa E., Hemp A. (2010) *Lunidia*, a new genus of African Phaneropterinae (Orthoptera: Tettigoniidae). Organisms, Diversity and Evolution 10(3): 215–226. DOI 10.1007/s13127-010-0004-4.

Hemp, C., Kehl, S., Heller, K.-G., Wägele, J. W., Hemp, A. (2010) A new genus of African Karniellina (Orthoptera, Tettigoniidae, Conocephalinae, Conocephalini): integrating morphological, molecular, and bioacoustical data. Systematic Entomology 35: 581–595.

Heller, K.-G., Ostrowski T. D., Hemp C. (2010) Singing and hearing in *Aerotegmina kilimandjarica* (Tettigoniidae: Hexacentrinae), a species with unusual low carrier frequency of the calling song. Bioacoustics 19(3): 195–210.

Hemp, C., Kehl, S. (2010) Taxonomic changes and new species of the flightless genus *Parepistaurus* Karsch, 1896 (Orthoptera: Acrididae, Coptacridinae) from mountainous East Africa. Journal of Orthoptera Research 19(1): 31–39.

Hemp, C. (2011) Faunistic relations between the ranges of the Eastern Arc mountains: relocation of *Peronura hildebrandtiana* Karsch, 1889 (Tettigoniidae: Phaneropterinae), the description of the male and implications from its phylogeographical pattern. Zootaxa 3006: 63–68.

Hemp, C. (2011) A new *Plagiotriptus* species (Orthoptera: Eumastacoidea, Thericleidae, Plagiotriptinae) from the Eastern Arc mountains of East Africa. Journal of Orthoptera Research 20(1): 97–101.

Helbig-Bonitz M., Rutten G., Kalko E. K. V. (2013) Fruit bats can disperse figs over different landuse types on Mount Kilimanjaro, Tanzania. African Journal of Ecology 52: 122–125.

Pabst H., Kühnel A., Kuzyakov Y. (2013) Effect of land-use and elevation on microbial biomass and water extractable carbon in soils of Mt Kilimanjaro ecosystems. Applied Soil Ecology 67: 10–19.

Voigt C. C., Helbig-Bonitz M., Kramer-Schadt S., Kalko E. K. V. (2013) The third dimension of bat migration: evidence for elevational movements of Miniopterus natalensis along the slopes of Mount Kilimanjaro. Oecologia 174: 751–761.

Zancolli G., Storfer A., Rödel M. O. (2013) Detection of *Batrachochytrium dendrobatidis* in River Frogs (Genus *Amietia*) on Mount Kilimanjaro, Tanzania. Herpetological Review 44: 611–614.

Schüler L., Hemp A., Zech W., Behling H. (2012) Vegetation, climate and fire-dynamics in East Africa inferred from the Maundi crater pollen record from Mt Kilimanjaro during the last glacial–interglacial cycle. Quaternary Science Reviews 39: 1–13.

Hemp, C., Kehl, S. Heller, K.-G., Wägele J. W., Hemp, A. (2012) Ecological adaptations of grassland-inhabiting flightless Orthoptera: *Fulvoscirtes* and *Acanthoscirtes*, two new genera of African Karniellina (Orthoptera, Tettigoniidae, Conocephalinae, Conocephalini). Systematic Entomology 37(2); 387–407. DOI: 10.1111/j.1365–3113.2012.00622.x

Laurance, W. F. et al. (2011) Global warming and the vulnerability of tropical biota. Biological Conservation 144: 548–557.

Hemp, A., Hemp, C. (2011) In: Liniger, H.P., R. Mekdaschi Studer, C. Hauert and M. Gurtner (Eds). Sustainable Land Management in Practice – Guidelines and Best Practices for sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO). Case Study: Chagga homegardens – Tanzania: 132–133.

Hemp, C. (2013) New *Phlugidia* species (Orthoptera: Tettigoniidae: Meconematinae, Phlugidini) from the Eastern Arc Mountains of Tanzania, Africa. Zootaxa 3670 (3): 378–384.

Hemp, C. (2013) Annotated list of Tettigoniidae (Orthoptera) from the East Usambara Mountains, Tanzania and new Tettigoniidae species from East Africa. Zootaxa 3737(4): 301–350. DOI 10.11646/zootaxa.3737.4.1

Hemp, C. (2013) A new *Loboscelian*a Dirsh species (Orthoptera: Pamphagidae: Porthetinae) from coastal Tanzania, East Africa. Zootaxa 3731 (2): 295–300. http://dx.doi.org/10.11646/zootaxa.3731.2.10.

Hemp, C. (2013) Annotated list of Ensifera (Orthoptera) and further records on Caelifera (Orthoptera) of Mt Kilimanjaro, Tanzania. Zootaxa 3613 (4): 301–342.

Hemp, C., Heller, K.-G., Warchalowska-Sliva, E., Grzywacz, B., Hemp A. (2013) Biogeography, ecology, acoustics and chromosomes of East African *Eurycorypha* Stål species (Orthoptera, Phaneropterinae) with the description of new species. Organisms, Diversity and Evolution. September 2013, Volume 13, Issue 3, pp 373–395. 10.1007/s13127-012-0123-1.

Hemp, C., Heller, K.-G., Warchalowska-Sliwa, E., Hemp, A. (2013) The genus *Aerotegmina* (Orthoptera, Tettigoniidae, Hexacentrinae): Morphological relations, phylogeographical patterns and the description of a new species. Organisms, Diversity and Evolution 13(4): 521–530. DOI 10.1007/s1317-013-0133-7.

Schüler L., Hemp A., Behling H. (2014) Pollen-based temperature and precipitation inferences for the montane forest of Mt Kilimanjaro during the last Glacial and the Holocene. Climate of the Past Discussions 10: 195–234.

Schüler L., Hemp A., Behling H. (2014) Relationship between vegetation and modern pollen-rain along an elevational gradient on Kilimanjaro, Tanzania. The Holocene 24: 702–713.

Zancolli G., Rödel M. O., Steffan-Dewenter I., Storfer A. (2014) Comparative landscape genetics of two river frog species occurring at different elevations on Mount Kilimanjaro. Molecular Ecology 23: 4989–5002.

Peters M. K., Mayr A., Röder J., Sanders N. J., Steffan-Dewenter I. (2014) Variation in nutrient use in ant assemblages along an extensive elevational gradient on Mt Kilimanjaro. Journal of Biogeography 41: 2245–2255.

Mganga K. Z., Kuzyakov Y. (2014) Glucose decomposition and its incorporation into soil microbial biomass depending on land-use in Mt Kilimanjaro ecosystems. European Journal of Soil Biology 62: 74–82

Classen A., Peters M. K., Ferger S. W., Helbig-Bonitz M., Schmack J. M., Maassen G., Schleuning M., Kalko E. K. V., Böhning-Gaese K., Steffan-Dewenter I. (2014) Complementary ecosystem services provided by pest predators and pollinators increase quantity and quality of coffee yields. Proceedings of the Royal Society B 281: 20133148.

Ferger S. W., Schleuning M., Hemp A., Howell K. M., Böhning-Gaese K. (2014) Food resources and vegetation structure mediate climatic effects on species richness of birds. Global Ecology and Biogeography 23: 541–549.

Zancolli G., Steffan-Dewenter I., Rödel M. O. (2014) Amphibian diversity on the roof of Africa: unveiling the effects of habitat degradation, altitude and biogeography. Diversity and Distributions 20: 297–308.

Heller, K.-G., Hemp, C. (2014) Fiddler on the tree - a bush-cricket species with unusual stridulatory organs and song. PLOS 01/2014 9(3): e92366. DOI: 10.1371/journal.pone.0092366.

Heller, K.-G., Hemp, C., Liu, C., Volleth, M. (2014) Taxonomic, bioacoustic and faunistic data on a collection of Tettigonioidea from Eastern Congo (Insecta: Orthoptera). Zootaxa 3786: 343–346.

Hemp, C., Heller, K.-G., Warchałowska-Sliwa, E., Hemp, A. (2014) Description of the female and notes on distribution, habitat, nymphal development, song and chromosomes of *Tropidonotacris grandis* Ragge (Orthoptera: Phaneropteridae). Zootaxa 3893 (4): 569–578. http://dx.doi.org/10.11646/zootaxa.3893.4.6

Dulle H.I., Ferger S.W., Cordeiro N.J., Howell K.M., Schleuning M., Böhning-Gaese K., Hof C. (2015) Changes in abundances of forest understorey birds on Africa's highest mountain suggest subtle effects of climate change. Diversity and Distributions 22: 288–299.

Becker J., Pabst H., Mnyonga J., Kuzyakov Y. (2015) Annual litterfall dynamics and nutrient deposition depending on elevation and land-use at Mt Kilimanjaro. Biogeoscience 12: 5635–5646.

Rutten G., Ensslin A., Hemp A., Fischer M. (2015) Vertical and horizontal vegetation structure across natural and modified habitat types at Mount Kilimanjaro. PLOS ONE 10: e0138822.

Ensslin A., Fischer M. (2015) Variation in life-history traits and their plasticities to elevational transplantation among seed families suggests potential for adaptative evolution of 15 tropical plant species to climate change. American Journal of Botany 102: 1371–1379.

Ferger S.W., Dulle H.I., Schleuning M., Böhning-Gaese K. (2015) Frugivore diversity increases frugivory rates along a large elevational gradient. Oikos 125: 245–253.

Helbig-Bonitz M., Ferger S.W., Böhning-Gaese K., Tschapka M., Howell K., Kalko E.K.V. (2015) Bats are not birds – Different responses to human land-use on a tropical mountain. BIOTROPICA 47: 497–508.

Mganga K.Z., Razavi B.S., Kuzjakov Y. (2015) Microbial and enzymes response to nutrient additions in soils of Mt Kilimanjaro region depending on land-use. European Journal of Soil Biology 69: 33–40.

Fischer R., Ensslin A., Rutten G., Fischer M., Schellenberger Costa D., Kleyer M., Hemp A., Paulick S., Huth A. (2015) Simulating Carbon Stocks and Fluxes of an African Tropi cal Montane Forest with an Individual-Based Forest Model. PLOS ONE 10: e0123300.

Ensslin A., Rutten G., Pommer U., Zimmermann R., Hemp A., Fischer M. (2015) Effects of elevation and land-use on the biomass of trees, shrubs and herbs at Mount Kilimanjaro. Ecosphere 6: 45.

Classen A., Peters M. K., Kindeketa W. J., Appelhans T., Eardley C. D., Gikungu M. W., Hemp A., Nauss T., Steffan-Dewenter I. (2015) Temperature versus resource constraints: which factors determine bee diversity on Mount Kilimanjaro, Tanzania? Global Ecology and Biogeography 24: 642–652.

Rutten G., Ensslin A., Hemp A., Fischer M. (2015) Forest structure and composition of previously selectively logged and non-logged montane forests at Mt Kilimanjaro. Forest Ecology and Management 337: 61–66.

Pabst H., Gerschlauer F., Kiese R., Kuzyakov Y. (2015) Land-Use and Precipitation Affect Organic and Microbial Carbon Stocks and the Specific Metabolic Quotient in Soils of Eleven Ecosystems of Mt Kilimanjaro, Tanzania. Land Degradation & Development 27: 592–602.

Appelhans T., Mwangomo E., Otte I., Detsch F., Nauss T., Hemp A. (2015) Eco-meteorological characteristics of the southern slopes of Kilimanjaro, Tanzania. International Journal of Climatology 36: 3245–3258.

Appelhans T., Mwangomo E., Hardy D.R., Hemp A., Nauss T. (2015) Evaluating machine learning approaches for the interpolation of monthly air temperature at Mt Kilimanjaro, Tanzania. Spatial Statistics 14: 91–113.

Enghoff H., Frederiksen S.B. (2015) A mountain of millipedes II: The genus Aquattuor Frederiksen, 2013 – five new species from the Udzungwa Mountains and one from Mt Kilimanjaro, Tanzania (Diplopoda, Spirostreptida, Odontopygidae). European Journal of Taxonomy 0: 150.

Kuppler J., Fricke J., Hemp C., Steffan-Dewenter I., Peters M.K. (2015) Conversion of savannah habitats to small-scale agriculture affects grasshopper communities at Mt Kilimanjaro, Tanzania. Journal of Insect Conservation 19: 509–518.

Hemp, C. (2015) Bushcrickets or Katydids (Orthoptera: Tettigonioidea), Locusts and grasshoppers (Orthoptera, Caelifera): 40–59. In: Holstein (ed.) Insects and allies of the Kakamega Forest National Reserve. A Field Guide for tourists and naturalists. BIOTA field guide, Stuttgart. 292 pp.

Hemp, C., Kehl, S., Schultz, O., Wägele, W., Hemp, A. (2015) Climatic fluctuations and topography as motor for speciation: case study on *Parepistaurus* Karsch, 1896 (Orthoptera: Acrididae, Coptacridinae). Systematic Entomology. 40(1): 17–34. DOI: 10.1111/syen.12092.

Hemp, C. Heller, K.-G., Warchalowska-Sliva, E., Grzywacz, B., Hemp, A. (2015) Biogeography, ecology, acoustics and chromosomes of the East African genus *Afroanthracites* Hemp & Ingrisch (Orthoptera, Tettigoniidae, Conocephalinae, Agraeciini) with the description of new species. Organisms, Diversity and Evolution. 15: 351–368. DOI 10.1007/s13127-014-0194-2.

Hemp, C., Heller, K.-G., Warchałowska-Sliwa, E., Hemp, A. (2015) A new species of *Philoscirtus* (Orthoptera: Phaneropteridae: Mecopodinae) from the West Usambara Mountains of Tanzania and its conservation status. Zootaxa 3905 (2): 273–282. http://dx.doi.org/10.11646/zootaxa.3905.2.8

Warchlowska-Sliwa, E., Grzywacz, B., Maryanska-Nadachowska, A., Hemp, A., Hemp, C., (2015) Different steps in the evolution of neo-sex chromosomes in two East African Spalacomimus species (Orthoptera: Tettigoniidae: Hetrodinae). European Journal of Entomology 112(1): 1–10. Doi: 10.14411/eje.2015.024

Hemp, C., Heller, K.-G., Elzbieta Warchlowska-Sliwa, Grzywacz, B., Hemp, A. (2015) Review of the *Plangia graminea* (Serville) complex and the description of new *Plangia* species from East Africa (Orthoptera: Phaneropteridae, Phaneropterinae) with data on habitat, bioacoustics and chromosomes. Organisms, Diversity and Evolution 15(3): 471–488. DOI 10.1007/s13127-015-0216-8.

Johns, P. M., Hemp, C. (2015) Redescription of *Libanasa brachyura* Karny, 1928. (Orthoptera: Anostostomatidae: ?Lutosinae) from Tanzania and problems at the subfamily level. Zootaxa 3946 (1): 113–124.

Heller, K.-G., Hemp, C., Ingrisch, S. Chunxiang, L. (2015) Acoustic Communication in Phaneropterinae (Tettigonioidea) – A Global Review with Some New Data. Journal of Orthoptera Research, 24(1):7–18.

Grzywacz, B., Hemp, C., Heller K.-G., Hemp, A.,Chobanov, D. P., Warchałowska-Sliwa, E. (2015) Cytogenetics and molecular differentiation in the African armoured ground bushcrickets (Orthoptera: Tettigoniidae: Hetrodinae). Zoologischer Anzeiger 259: 22–30.

Rowell, C. H. F., Hemp, C., Harvey, A. W. (2015) Jago´s Grasshoppers of East and North East Africa. Volume 1: Pneumoridae, Pyrgomorphidae, Lentulidae, Pamphagidae and Dericorythidae. Blurb Publishers. ISBN 978-1-32-046414-7.

Hemp, C., Johns, P. (2015) *Libanasa kilomeni*, a new species of East African Lutosinae (Orthoptera: Anostostomatidae). Zootaxa 4032 (4): 435–443. http://dx.doi.org/10.11646/zootaxa.4032.4.8

Peters M.K., Hemp A., Appelhans T., Behler C., Classen A., Detsch F., Ensslin A., Ferger S.W., Frederiksen S.B., Gebert F., Haas M., Helbig-Bonitz M., Hemp C., Kindeketa W.J., Mwangomo E., Ngereza C., Otte I., Röder J., Rutten G., Schellenberger Costa D., Tardanico J., Zancolli G., Deckert J., Eardley C.D., Peters R.S., Rödel M-O., Schleuning M., Ssymank A., Kakengi V., Zhang J., Böhning-Gaese K., Brandl R., Kalko E.K.V., Kleyer M., Nauss T., Tschapka M., Fischer M., Steffan-Dewenter I. (2016) Predictors of elevational biodiversity gradients change from single taxa to the multi-taxa community level. Nature Communications 7: 13736.

Becker J.N., Gütlein A., Sierra Cornejo N., Kiese R., Hertel D., Kuzyakov Y. (2016) Legume and Non-legume Trees Increase Soil Carbon Sequestration in Savanna. Ecosystems 20: 989–999.

Röder J., Detsch F., Otte I., Appelhans T., Nauss T., Peters M. K., Brandl, R. (2016) Heterogeneous patterns of abundance of epigeic arthropod taxa along a major elevation gradient. Biotropica 49: 217–228.

Blagodatskaya E., Blagodatsky S., Khomyakov N., Myachina O., Kuzyakov Y. (2016) Temperature sensitivity and enzymatic mechanisms of soil organic matter decomposition along an altitudinal gradient on Mount Kilimanjaro. Scientific Reports 6: Article number 22240.

Mganga K., Razavi B.S., Kuzyakov Y. (2016) Land-use affects soil biochemical properties in Mt Kilimanjaro region. Catena 141: 22–29.

Hemp A., Zimmermann R., Remmele S., Pommer U., Berauer B., Hemp C., Fischer M. (2016) Africa's highest mountain harbours Africa's tallest trees. Biodiversity and Conservation 26: 103–113.

Gütlein A., Zistl-Schlingmann M., Becker J. N., Cornejo N. S., Detsch F., Dannenmann M., Appelhans T., Hertel D., Kuzyakov Y., Kiese R. (2016) Nitrogen turnover and greenhouse gas emissions in a tropical alpine ecosystem, Mt Kilimanjaro, Tanzania. Plant Soil 411: 243–259.

Detsch F., Otte I., Appelhans T., Hemp A., Nauss T. (2016) Seasonal and long-term vegetation dynamics from 1-km GIMMS-based NDVI time series at Mt Kilimanjaro, Tanzania. Remote Sensing of Environment 178: 70–83.

Detsch F., Otte I., Appelhans T., Nauss T. (2016) A comparative study of cross-product NDVI dynamics in the Kilimanjaro region – a matter of sensor, degradation calibration, and significance. Remote Sensing 8: 159.

Gerschlauer F., Dannenmann M., Kühnel A., Meier R., Kolar A., Butterbach-Bahl K., Kiese R. (2016) Gross Nitrogen Turnover of Natural and Managed Tropical Ecosystems at Mt Kilimanjaro, Tanzania. Ecosystems 19: 1271–1288.

Rutten G., Prati D., Hemp A., Fischer M. (2016) Plant-soil feedback in East-African svanna trees. Ecology 97: 294–301.

Gütlein A., Dannenmann M., Kiese R. (2016) Gross nitrogen turnover rates of a tropical lower montane forest soil: Impacts of sample preparation and storage. Soil Biology & Biochemistry 95: 8–10.

Hemp, C. (2016) The Eastern Arc Mountains and coastal forests of East Africa – an archive to understand large-scale biogeographical patterns: Pseudotomias, a new genus of African Pseudophyllinae (Orthoptera: Tettigoniidae). Zootaxa 4126 (4): 480 –490.

Gereau, R. E., Cumberlidge, N., Hemp, C., Hochkirch, A., Jones, T., Kariuki, M., Lange, C. N., Loader, S. P., Malonza, P. K., Menegon, R., Ndang´ang´a, P. K., Rovero, F., Shirk, P. (2016) Globally threatened biodiversity of the Eastern Arc Mountains and coastal forests of Kenya and Tanzania. Journal of East African Natural History 105(1): 115–201.

Hemp, C., Heller, K.-G., Warchałowska-Sliwa E., Hemp, A. (2016) Spotted males, uniform females and the lowest chromosome number in Tettigoniids recorded: Review of the genus *Gonatoxia* Karsch (Orthoptera: Phaneropterinae). Deutsche Entomologische Zeitschrift 63(2): 271–286. https://doi.org/10.3897/dez.63.10799

Uyehara, I. K., Sisanya, M., Hemp, C., Rubenstein, D.I. (2016) Effects of traditional pastoralism on grasshopper (Caelifera) assemblages in East Africa. African Journal of Ecology 54 (2): 167–173. Doi: 10.1111/aje.12279

Hemp, C., Grzywacz, B., Warchałowska-Sliwa, E., Hemp, A. (2016) Topography and climatic fluctuations boosting speciation: biogeography and a molecular phylogeny of the East African genera *Afroanthracites* Hemp & Ingrisch and *Afroagraecia* Ingrisch & Hemp (Orthoptera, Tettigoniidae, Conocephalinae, Agraeciini). Organisms, Diversity and Evolution. 16(1), 211–223. DOI: 10.1007/s13127-015-0244-4

Schüler, L., Hemp, A., (2016) Atlas of pollen and spores and their parent taxa of Mt Kilimanjaro and tropical East Africa. Quaternary International 425, 301–386.

Heller, K.-G., Hemp C. (2017) Context specific signaling with different frequencies – directed to different receivers? A case study in *Gonatoxia* katydids (Orthoptera, Phaneropteridae). Journal of Insect Behavior. 30(4), 420–431. Doi:10.1007/s10905-017-9628-y.

Hemp, C., Ingrisch, S., Heller K.-G. (2017) A new genus and other new species of Agraeciini from the Eastern Arc Mountains, East Africa (Orthoptera: Tettigoniidae; Conocephalinae; Agraeciini). Zootaxa 4311 (1): 001–022.

Hemp, C., Heller K.-G., Warchalowska-Sliwa, E. (2017) New genera and new species of Acrometopini from East Africa and a review of all known stridulatory organs, songs and karyotypes of the tribe (Orthoptera: Tettigoniidae Phaneropterinae). Insect Systematics & Evolution. DOI 10.1163/1876312X-00002170

Hemp, C., Heller, K.-G., Hemp, A., Warchalowska-Sliwa, E., Grzywacz, B. (2017) A molecular phylogeny of East African *Amytta* (Orthoptera: Tettigoniidae, Meconematinae) with data on their karyotypes. Systematic Entomology. DOI: 10.1111/syen.12269.

Hemp, C. (2017) Review of the genus *Lunidia* Hemp (Orthoptera: Phaneropteridae) and the description of a new species from the Uluguru Mountains of Tanzania, East Africa. Journal of Orthoptera Research 26(2): 85–89.

Hemp, C. (2017) New *Eurycorypha* species (Orthoptera: Tettigonoidea: Phaneropteridae; Phaneropterinae from East Africa. Zootaxa 4358 (3): 471–493.

Hemp, C., Massa, B. (2017) Review of the African genera Arantia Stål and Goetia Karsch (Orthoptera: Tettigoniidae: Phaneropterinae). Zootaxa: 4362 (4): 451–498. https://doi.org/10.11646/zootaxa.4362.4.1

Schellenberger Costa D., Classen A., Ferger S., Helbig-Bonitz M., Peters M., Böhning-Gaese K., et al. (2017) Relationships between abiotic environment, plant functional traits, and animal body size at Mount Kilimanjaro, Tanzania. PLoS ONE 12: e0174157.

Classen A., Steffan-Dewenter I., Kindeketa W., Peters M.K. (2017) Integrating intraspecific variation in community ecology unifies theories on body size shifts along climatic gradients. Functional Ecology 31: 768–777.

Hemp, C., Heller, K.-G. (2017) Revision of the genus *Amytta* (Orthoptera: Tettigoniidae, Meconematinae) and new species from East Africa. Zootaxa 4263 (2): 295–317.

Mollel N.P., Fischer M., Hemp A. (2017) Usable wild plant species in relation to elevation and land-use at Mount Kilimanjaro, Tanzania. Alpine Botany 127: 145–154.

Ensslin A., Mollel N.P., Hemp A., Fischer M. (2017) Elevational transplantation suggests different responses of African submontane and savanna plants to climate warming. Journal of Ecology DOI: 10.1111/1365-2745.12842.

Detsch F., Otte I., Appelhans T., Nauss T. (2017) A glimpse at short-term controls of evapotranspiration along the southern slopes of Kilimanjaro Environ Monit Assess 189: 465.

Vollstädt M.G.R., Ferger S., Hemp A., Howell K.M., Töpfer T., Böhning-Gaese K., Schleuning M. (2017) Direct and indirect effects of climate, human disturbance and plant traits on avian functional diversity. Global Ecol Biogeogr. 00: 1–10.

Hemp, C., Heller, K.-G., Warchałowska-Sliwa, E., Grzywacz, B., Hemp, A. (2017) Review of the East African species of the phaneropterine genus *Parapyrrhicia* (Insecta: Orthoptera): Secret communication of a forest bound taxon with data on morphology, ecology and chromosomes, including the description of new species. Organisms Diversity and Evolution 17(1), 231–250. DOI 10.1007/s13127-016-0303-5.

Hemp, C. (2017) Annotated checklist of Orthoptera from Kazimzumbwi Forest Reserve, Tanzania with the description of new species and discussion of the biogeographic patterns of threatened species. Zootaxa 4226 (2): 151–193. https://doi.org/10.11646/zootaxa.4226.2.1

Hemp, C. (2017) New species of Lentulidae and Tettigoniidae (Orthoptera) from the Udzungwa Mountains, Tanzania. Zootaxa 4227 (2): 233–250. https://doi.org/10.11646/zootaxa.4227.2.5

Hemp, C. Heller, K.-G. (2017) The genus *Phlesirtes* Bolivar, 1922 (Orthoptera: Tettigoniidae: Conocephalinae, Conocephalini), a mountain adapted taxon of Karniellina: a review of the genus with data on its bioacoustics and the description of new species. Zootaxa 4244 (4): 451–477.

Otte I., Detsch F., Gütlein A., Scholl M., Kiese R., Appelhans T., Nauss T. (2017) Seasonality of stable isotope composition of atmospheric water input at the southern slopes of Mt Kilimanjaro, Tanzania. Hydrological Processes 31: 3932–3947.

Getzin S., Fischer R., Knapp N., Huth A. (2017) Using airborne LiDAR to assess spatial heterogeneity in forest structure on Mount Kilimanjaro. Landscape Ecology 32: 1881–1894.

Otte I., Detsch F., Mwangomo E., Hemp A., Appelhans T., Nauss T. (2017) Multidecadal Trends and Interannual Variability of Rainfall as Observed from Five Lowland Stations at Mt Kilimanjaro, Tanzania. Journal of Hydrometeorology 18: 349–361.

Kühnel A., Bogner C. (2017) In-situ prediction of soil organic carbon by vis–NIR spectroscopy: an efficient use of limited field data. European Journal of Soil Science 68: 795–1002.

Gütlein A., Gerschlauer F., Kikoti I, Kiese R. (2018) Impacts of climate and land-use on N2O and CH4 fluxes from tropical ecosystems in the Mt Kilimanjaro region, Tanzania. Global Change Biology 24: 1239–1255.

Hemp A., Hemp C. (2018) Broken bridges: The isolation of Kilimanjaro's ecosystem. Global Change Biology. DOI: 10.1111/gcb.14078.

Mganga K.Z., Kuzyakov Y. (2018) Land- use and fertilisation affect priming in tropical andosols. European Journal of Soil Biology 87: 9–16.

Heller K.-G., Hemp, C. (2018) Extremely divergent song types in the genus *Aerotegmina* Hemp (Orthoptera: Tettigoniidae: Hexacentrinae) and the description of a new species from the Eastern Arc Mountains of Tanzania (East Africa). Bioacoustics. ISSN: 0952-4622 (Print) 2165-0586 (Online) Journal homepage: http://www.tandfonline.com/loi/tbio20.

Becker J.N., Kuzyakov Y. (2018) Teatime on Mount Kilimanjaro: Assessing climate and land-use effects on litter decomposition and stabilization using the Tea Bag Index. Land Degradation & Development. DOI: 10.1002/ldr.2982.

Schellenberger Costa D., Zotz G., Hemp A., Kleyer M. (2018) Trait patterns of epiphytes compared to other plant life-forms along a tropical elevation gradient. Functional Ecology. DOI: 10.1111/1365-2435.13121.

Hemp C., Hemp, A. (2018) Conservation Status of the Elegant Yellow-Black Bush-cricket (*Meruterrana elegans*) (Orthoptera: Phaneropterinae) – a critically endangered species on Mt Kenya. Journal of East African Natural History 107(1): 9–16.

Rowell H.F., Jago N., Hemp C. (2018) Revision of *Aresceutica*, Karsch 1896 (Orthoptera, Acridoidea, Catantopinae) with comments on related genera. Journal of Orthoptera Research 27(2): 107–118.

Tiede, Y., Hemp, C., Schmidt, A., Nauss, T., Farwig, N., Brandl, R. (2018) Beyond body size: Consistent decrease of traits within orthopteran assemblages with elevation. Ecology. doi: 10.1002/ecy.2436.

Rowell, C.H.F., Hemp, C. (2018) Jago´s grasshoppers & locusts of East and North East Africa: An identification Handbook. Volume 3. Acrididae: Catantopinae. Blurb Publishers. ISBN: 9781388205515.

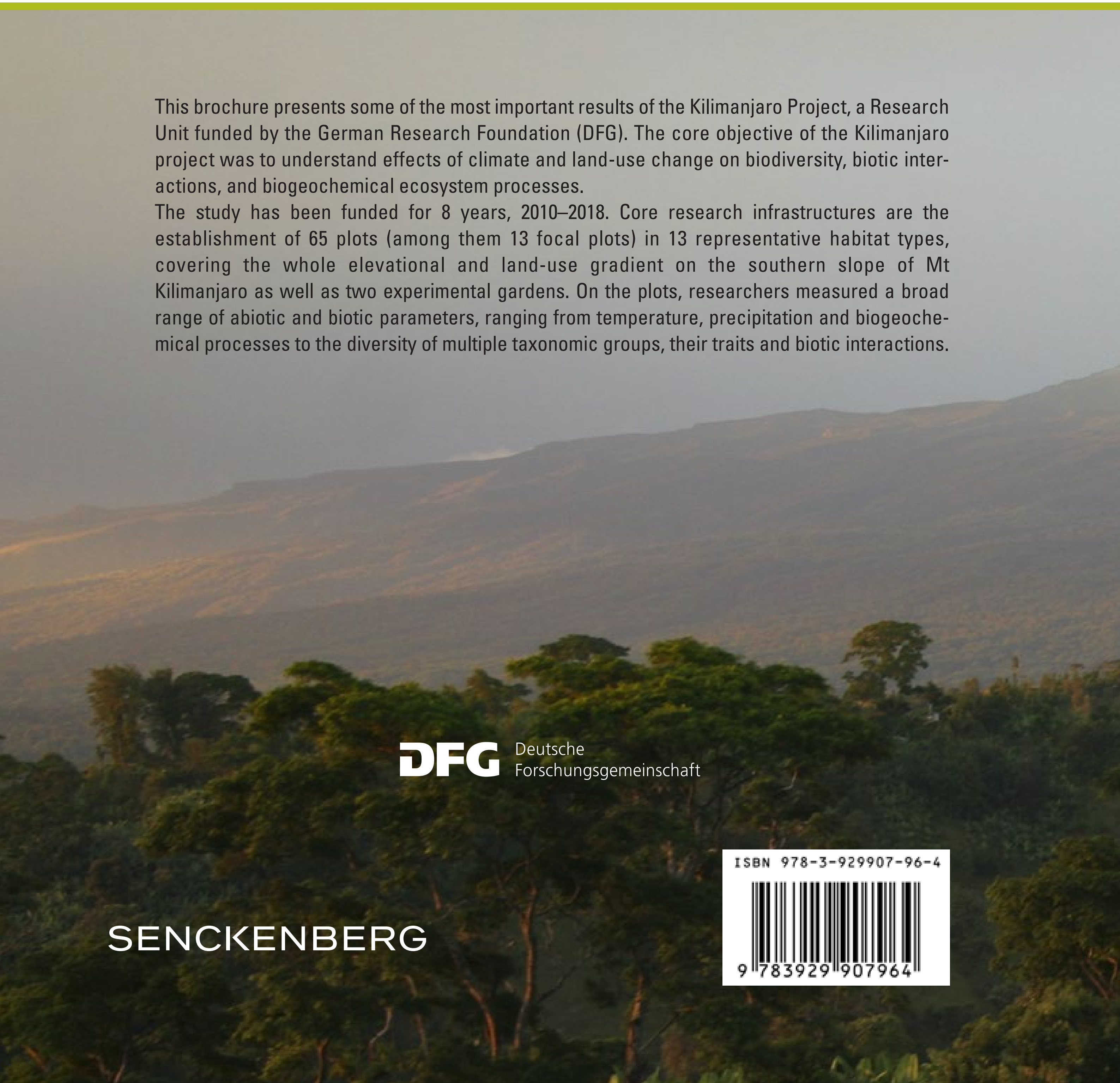
Albrecht J., Classen A., Vollstädt M. G. R., Mayr A., Mollel N. P., Schellenberger Costa D., Dulle H. I., Fischer M., Hemp A., Howell K. M., Kleyer M., Nauss T., Peters M. K., Tschapka M., Steffan-Dewenter I., Böhning-Gaese K. & Schleuning M. (2018) Plant and animal functional diversity drive mutualistic network assembly across an elevational gradient. Nature Communications 9: 3177.

Photo credits:

Cover pages: Andreas Hemp. Page 6: Claudia Hemp. Pages 7 & 8: Claudia Hemp. Page 9: left image Andreas Hemp, left column, middle: Claudia Hemp; right image: Andreas Hemp. Page 10: Andreas Hemp. Page 11: Claudia Hemp. Page 12: left images: Claudia Hemp, drawing right column Andreas Hemp. Pages 13–15: Claudia Hemp. Page 16: Claudia Hemp, except for bushcricket drawing: Andreas Hemp. Pages 17–21: Claudia Hemp. Pages 24–27: Andreas Hemp. Page 29: Figs. 2 & 5 Andreas Hemp, Fig 3. Claudia Hemp, Fig. 4 Ulf Pommer. Pages 30–31: Claudia Hemp. Page 32: Fig. 11 Andreas Hemp, Figs. 12 & 13 Claudia Hemp. Pages 33–34: Andreas Hemp. Page 35: Jie Zhang. Pages 36–45: Insa Otte except for Figs. 2 & 3 page 39 and Figs. 2 & 3 page 43 Claudia Hemp. Pages 46–50: Natalia Sierra-Cornejo, except for Fig. 8 page 50 Claudia Hemp. Pages 51–54: Jerome Kimaro. Page 55–56: Joscha Becker. Pages 57 & 60: Claudia Hemp. Pages 61–63: Ralf Kiese. Page 64 & 65: Reiner Zimmermann & Sabine Remmele. Pages 66–67: Claudia Hemp, except Fig. 4 page 67 Andreas Hemp. Pages 68–73: Andreas Hemp, except Fig. 5 page 71 Claudia Hemp. Page 74: Jukka Korpelainen. Pages 75–78: Marion Renner, except Figs. 2 & 3 page 77 Claudia Hemp. Pages 79–83 Andreas Ensslin. Pages 84–86: Rafael Molina-Venegas. Pages 87–88: Nedovotu Mollel, except Fig. 3 Andreas Hemp and Figs. 4–6 Claudia Hemp. Pages 89–90: Pekka Hurskainen, except Fig. 3 Claudia Hemp. Pages 91–95: Lisa Schüler-Goldbach, except Fig. 2 page 93 Hermann Behling. Pages 96–97: Vincent Montade, except Fig. 9 page 97 Andreas Hemp. Page 98: Claudia Hemp. Pages 99–101: Michael Kleyer, except Fig. 6 page 101 Claudia Hemp. Page 103: Hawa Mushi. Page 104: Claudia Hemp. Pages 105–106: Friedrich Bohn. Pages 107–113: Anna Vogeler & Maria Helbig, except Fig. 5 page 109 Claudia Hemp. Page 114: Maximilian Vollstädt. Page 115: Claudia Hemp. Page 116–121: Maximilian Vollstädt & Claudia Hemp. Pages 122–123: Alice Claßen, except Fig. 1 Friederike Gebert. Pages 124–125: Friederike Gebert. Pages 126–129: Claudia Hemp, except Fig. 7 page 129 A. Illum. Pages 130–133: Juliane Röder, except Fig. 4 page 133 Claudia Hemp. Pages 134–136: Giulia Zancolli, except Figs. 6 & 9 page 135 and Figs. 12 & 13 page 136 Claudia Hemp. Page 137–145: Claudia Hemp, except Fig. 9 page 145 Andreas Hemp. Pages 146–152: Claudia Hemp, except Fig. 7 page 149 Gülsah Koch and Fig. 1 page 152 Andreas Hemp. Page 154: Claudia Hemp, except Fig. 1 Andreas Hemp. Page 156: Claudia & Andreas Hemp.

Our partners:

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
UNIVERSITÄT BAYREUTH
Philipps Universität Marburg
ulm university universität uulm
CARL VON OSSIETZKY universität OLDENBURG
National Museums of Tanzania (NMT)
SOKOINE UNIVERSITY OF AGRICULTURE 1984 ARDHI NI HAZINA
HIFADHI ZA TAIFA TANZANIA NATIONAL PARKS
TAWIRI Tanzania Wildlife Research Institute
NATIONAL MUSEUMS OF KENYA
WHERE HERITAGE LIVES ON
UNIVERSITÄT BERN
KIT Karlsruher Institut für Technologie
HELMHOLTZ ZENTRUM FÜR UMWELTFORSCHUNG UFZ
TROPICAL PESTICIDES RESEARCH INSTITUTE TPRI
Julius-Maximilians-UNIVERSITÄT WÜRZBURG
UNIVERSITÄT HOHENHEIM



This brochure presents some of the most important results of the Kilimanjaro Project, a Research Unit funded by the German Research Foundation (DFG). The core objective of the Kilimanjaro project was to understand effects of climate and land-use change on biodiversity, biotic interactions, and biogeochemical ecosystem processes.

The study has been funded for 8 years, 2010–2018. Core research infrastructures are the establishment of 65 plots (among them 13 focal plots) in 13 representative habitat types, covering the whole elevational and land-use gradient on the southern slope of Mt Kilimanjaro as well as two experimental gardens. On the plots, researchers measured a broad range of abiotic and biotic parameters, ranging from temperature, precipitation and biogeochemical processes to the diversity of multiple taxonomic groups, their traits and biotic interactions.

DFG Deutsche
Forschungsgemeinschaft

SENCKENBERG

ISBN 978-3-929907-96-4
9 783929 907964