Wetlands in East Africa:
Reconciling future food production with environmental protection

Annual progress report
(January 2015 – December 2015)
Food production in many upland areas in East Africa shows stagnating or declining trends. On the other hand, a year-round or seasonal water availability and generally high resource base quality make wetlands potential production hotspots. With a cover of nearly 20 Mio ha in the four target countries and only about half of them currently being used, we surmise that wetlands become the food basket of the region. However, an increased food production from wetlands will only be achieved sustainably if agricultural land use can be reconciled with the conservation of biodiversity and the maintenance of ecosystem services. In a trans-disciplinary research approach, a consortium from Bonn-Cologne-Jülich-Mainz and several African partners assesses wetlands’ contribution to food security and the sustainability of current and projected future uses. We study spatial-temporal dynamics of matter fluxes and their underlying processes and assess technical options for enhancing production while considering ecosystem services. Models and various assessment and decision tools are developed and employed for cross-scale integration and regional projections under different global change scenarios. The integration of actors from development and policy into the research process and a strong capacity building component ensure the application of the findings both within the region studied and beyond. The present report has been prepared for the 2016 General Assembly Meeting of the GlobE-Wetlands project and covers the period from January to December 2015. Besides the general background, it contains selected key findings and achievement. Despite a delayed start of field research activities with the onset of the rainy season 2014, most milestones have been achieved.

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Introduction

The food security challenges in Africa can be summarized in two key questions: (1) how to maintain and enhance food production while minimizing negative side effects? and (2) how to sustainably increase productivity when millions are still short of food? (Godfray et al., 2010). The “Wetland” project will provide answers to these crucial questions through collaborative and trans-disciplinary research in an African-German consortium. Large unused wetland reserves, prolonged periods of water availability and relatively fertile soils contribute to the potential of wetlands for the expansion and intensification of agricultural production. However, a sustainable increase in wetland-based food security will only be achieved if the benefits accrued from wetland services can be reconciled with the requirement for increased food production. Sustainable use options differ according to country and region, specific attributes of the wetland and its users, and the social-ecological environment (Finlayson and van der Valk, 2012). We propose a strategy aimed at promoting a wise use of wetlands in Kenya, Rwanda, Tanzania and Uganda. The suggested approaches involve cross-scale trans-disciplinary research, combining field experiments and surveys with modelling approaches and the assessment of regional and global change scenarios. Guidelines and tools are being developed to provide answers as to where and how wetlands may be used in a sustainable way to become the future food basket of the region while fulfilling essential functions and providing diverse ecosystem services.

The food security challenges

Improving food security and resource use in agricultural production are closely interlinked challenges, relying on the available natural resource base and the management of agroecosystems (Foley et al., 2011). Food security is given when sufficient food is available, accessible, utilizable, and steadily provided (Wheeler and von Braun, 2013). Thus, future crop production will need to respond to multiple demands from a societal, environmental and agronomic perspective. Current projections show a continued increase of world population from about 6.8 billion people in 2010 to 9.1 billion by 2050, with sub-Saharan Africa (SSA) leading the way, as its population is projected to double from 856 million inhabitants in 2010 to approximately 1.96 billion by 2050 (Godfray et al., 2010). On the one hand, this represents a powerful driving force to intensify land use for food production (Tscharntke et al., 2012); on the other hand, recurrent episodes of sharp increases in staple food prices and increasing rainfall variability are inflicting serious damage on the food security of the poorest households (IFAD, 2010). Production potentials are increasingly limited by soil nutrient depletion and erosion of upland areas. About half of the agriculturally used land is affected by drought and nearly 80% is characterized by unfavourable soil conditions (Millennium Ecosystem Assessment, 2005). Intensified land use further exacerbates soil-related and pest problems, and climate change leads to shorter return periods of extreme climatic events, thus increasing farmers’ exposure to climate-related welfare losses. However, agriculture remains a powerful engine for economic growth, food security and poverty reduction, and unlike Asia, Africa still possesses a large reservoir of underutilized agricultural resources, of which wetland areas are the most promising. Thus, we assume that agriculture will play a significant role in ensuring regional food security in the coming decades, mainly through an intensified, yet wise use of wetlands that reconciles the needs for increased food production with growing concern for the environment.

The wetland alternative

Wetlands in SSA consist mainly of inland valley swamps and alluvial floodplains making up > 80% of East Africa’s total wetland area and covering > 18 Mio ha in Kenya, Rwanda, Uganda and Tanzania. Their conversion into sites of production has been largely responsible for the recent increases in per-capita food production and the decline in the number of undernourished people and generates food for urban communities and income for thousands of farm families (FAO-STAT, 2015). On the other hand, this land conversion is also responsible for a loss in biodiversity and a severe reduction in the provision of diverse ecosystem services. The price for such gains in food security and employment is thus often being paid for by the destruction of habitats and the loss of ecosystem services of so far unknown dimension (Boyd and Banzhaf, 2007). The Millennium Ecosystem Assessment (2005) defines wetland services as the ”benefits people obtain from wetland ecosystems”, comprising of provisioning services (i.e., food and water), regulating services (i.e., climate, natural hazards), cultural services (i.e., spiritual, recreational), and supporting services (i.e., soil formation, nutrient cycling). Wetlands also play a key role in the conservation of biodiversity and as habitats for wildlife. They are buffers and storage areas for water, and some 45 Petagrams of carbon are stored in wetland soils in sub-Saharan Africa (Mitch et al., 2012). Many wetlands are considered sites of great cultural value, and, in dry areas, they are important grazing grounds for landless herders during the dry season (Sayre et al., 2013). Sustainable agricultural uses must consider this multi-functional nature of wetlands, taking into account the aims and aspirations of diverse stakeholders (Obst et al., 2015).

The study areas

The choice of intervention areas for the “Wetlands” project, are based on a set of biophysical and socioeconomic attributes, and on national policy priorities. They comprise floodplains in the semi-arid highlands (Ewaso Narok swamp in Kenya) the sub-humid lowlands (Kilombero valley in Tanzania), as well as inland valley swamps along an urban-rural
gradient (Kampala - Namulonge in Uganda) and an altitude gradient (Nyavarungu River around Kigali, Rwanda). Covering the prevailing diversity, the selected wetlands are ideal for conducting field experiments and surveys, providing the required attributes for trans-disciplinary data integration and modelling, and being representative to allow for up-scaling activities. Being national priority environments, research at these sites solicits political interest and is seen to facilitate data transfer from science into the application arena.

**Goals and objectives**

The overall aim is to assess the potential for sustainably transforming wetlands into the food basket of East Africa, and to develop science-based tools, facilitating this process. This aim translates into four major goals, which are addressed at different scales. We hypothesize that wisely used wetlands will become the future food basket of East Africa. We surmise that the required food production increases can be reconciled with concerns for nature protection and the maintenance of ecosystem services through site specific constraint analysis and the system-specific development and extrapolation of production methods. The development of guidelines leading to such wise use requires cross-scale assessment and integrated trans-disciplinary modelling strategies. The “Wetland” project is thus developing a set of products that contribute to decision making (protection vs. use), guide land use planning, and inform policy (Figure 1, Annex).

**Project structure**

Achieving these goals and ascertaining if and how wetlands may become the food basket of East Africa requires collaborative and trans-disciplinary research (Figure 2, Annex). It entails conducting studies on the current state and uses of wetlands and the underlying processes (cluster A: Status quo), the identification of adapted wetland use scenarios (cluster B: Management options), the assessment of potential future wetland uses (cluster C: Integration and scenarios), and spatial targeting and up-scaling (cluster D: Extrapolation and recommendation). This structure is complemented with diverse training activities, the provision of decision-making tools, and multi-stakeholder workshops (cluster E: Capacity-building). (Table 1). The cooperation follows a trans-disciplinary multi-stakeholder approach based on partnerships. The network structures in place are characterized by the mutual complementary and disciplinary expertise in the fields of socio-economy (resource and institutional economics, social anthropology, policy economics, social geography), resource management (biodiversity, hydrology, hydrogeology, meteorology, soil science), agronomy (crop sciences, plant nutrition rice production, organic agriculture) and human health (public health, water quality). The project benefits from the experiences of long-term collaboration gained through diverse joint research projects. The following sections present results or achievements of selected activities from the year 2015 (reporting period).

**Table 1.** Research clusters and work packages of the GlobE Wetlands project, including goals, scales of intervention

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<td><strong>Goal:</strong> Training and Capacity Building</td>
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References


2 ADMINISTRATIVE ACTIVITIES

2.1 Project management and organization

The complexity of the subject and the diversity of involved players, as well as our expectation to make a contribution to regional food security require a governance structure with clearly defined roles and shared responsibilities at both the strategic and the operational level of planning and implementation. The following bodies of governance are operational:

“Speaker” The speaker (M. Becker) and his deputy (B. Diekkrüger) are correspondents and responsible for the communication with the donor and the executive organization of the initiative and take responsibility for over-arching coordination activities. They are supported by a technical coordinator (Eike Kiene - 100% position) and an administrative secretary (Susanne Hermes- 20% position) in the central project office.

“Advisory board” The contributions of the project goals and activities to both national and international research and development priorities are being checked upon and corrected if required in the annual meeting. The board is made up by decision makers from the four member countries and Germany: Rose Mukankomeje – REMA, Ministry of Environment Rwanda; Alice Kaudia – Ministry of Environment and Mineral Resources, Kenya; Richard Kyambadde – Ministry of Environment, Uganda; Julius Kenneth Ningu – Vice Presidents Office, Tanzania; Ludwig Kammesheidt - International Office of the German Federal Ministry for Science and Education. The board meets yearly in November (2014 Kenya, 2015 Uganda, 2016 Rwanda – planned).

“Country Coordinators” They support the country activities logistically, provide back-stopping and administer funds. They also contribute to the scientific priority setting as members in the Steering Committee. Country Coordinators are H. Oyieke – Kenya; M. Ugen – Uganda; D. Sebashongore – Rwanda; and S. Misana – Tanzania.

“Steering Committee” It decides on the scientific / technical priorities and approves research activities at the work package level. It is composed of the Speakers, Country Coordinators, and the CGIAR partner and meets annually.

Funding of the GlobE-Wetland project was approved in July 2013. While the project started officially with a kick-off workshop in Tanzania in September 2013, field research commenced only with the onset of the rainy season in 2014.

Physical infrastructure: A coordination office in Bonn has been obtained from the university and was furnished with funds from the Faculty of Agriculture and the INRES Institute. It is located in the center of the campus of the Agricultural University in Bonn (Nussallee 1). It houses the technical coordinator and also the three Bonn-based post-docs. Additional facilities are available for accommodating visiting scientists. The central coordination office also houses the computer back-up and the project communication infrastructure. The high-performance central server was established. It is synchronized with the server at Makerere University. Five automated climate stations have been procured and installed at the super test sites as well as in the Ewaso Narok swamp in Kenya. Climate stations provide essential data for crop simulation modelling, hydrology, climatology, regional extrapolation. The stations collect data at 10-minute intervals and relay them to the central server facility in Uganda.

Administration and Organization: Legal agreements that govern the collaboration have been prepared and signed by all collaborating organizations. Research priorities have been set at the kick-off meeting with 50 participants in Dar-es-Salaam. These priorities and the methodological approaches are being revised, refined and harmonized at the annual General Assembly Meeting. Basic research equipment for all project sites (ovens, mills, soil-water station, sampling and chemical analytical equipment, etc.) has been purchased and sent to the target countries. Fully functional project houses providing accommodation and means to conduct research are established and operational in all countries.

The central coordination office organizes monthly staff and student meetings. At these meetings, organizational issues are discussed, students present their work plans or preliminary findings, methodological approaches are harmonized, and priorities and collaboration needs for field research activities are defined. The minutes are shared with all GlobE-Wetlands members and are posted on the internal GlobE-Wetlands website. Additionally, an annual general assembly for all staff and students is organized by the central coordination office. The last general assembly 2015 took place in March and was used to present and discuss findings and to plan and adapt ongoing and future transdisciplinary activities.

The web-site (http://www.wetlands-africa.de/) is being updated weekly. Besides general information about the project, details on the study regions, publications and presentations and a list of contacts, the site has an internal page where the approved proposal, progress reports, students’ profiles, and the minutes of the monthly meetings are accessible. Via the internal page, members can also access the central database.
3 RESEARCH ACTIVITIES AND KEY FINDINGS

3.1 Cluster A: Status quo and function of wetlands

Analyzing the potential for wetlands to become the future food baskets of East Africa or rather sites of protection requires, firstly, an improved understanding of the diverse types and use systems in major wetlands, the trade-offs associated with the conversion of semi-natural land to agricultural use, and the processes that underlie both the driving forces of use changes and the processes determining ecosystem services and the production potential of key wetland commodities. We evaluated and quantified the production potential of specific wetland situations, investigated the processes involved at multiple scales, and are in the process of evaluating the relative merits of food production against those of other ecosystem services. Cluster A forms the basis of most research activities conducted in clusters B, C and D. Here we answer the essential questions that define the current state of resource availability, uses and users, and identify the processes defining the resilience and vulnerability of wetland systems. This knowledge of the status quo and the functioning of wetlands is guiding the selection, testing and targeting of new management options and provides the quantitative basis for understanding their environmental and economic effects. The key research questions to be answered in cluster A are: (i) What are the characteristics of different key wetland types?; (ii) What is the potential for agricultural production and what are the major biophysical constraints in different regions?; (iii) What is the socio-economic background of the people living in and in close proximity to these wetlands, and how do the wetlands contribute to food security?; (iv) What are the ecosystem services provided by these wetlands, and what is their ecological and economic “value”?: and (v) What are the water and matter fluxes within different wetland types and use systems, and how do they affect soil quality and water-associated human health risks? This work is done jointly by biophysical, social, and cultural scientists reflecting the need for a trans-disciplinary approach.

WP-A1: Wetland characterization and typology

Abstract: To guide the selection of representative target sites and to develop management strategies, there is the need for a systematic characterization and classification of homogenous wetland sub-units. We combine interdisciplinary assessments and participative appraisals for gathering data about biophysical and socio-economic attributes, about the driving forces for wetland uses and about attributes affecting the vulnerability of agro-ecosystems. A classification of assessment (use) units has been developed and published. It is currently being implemented in an expert system able to classify further units.

Objectives: We hypothesize that the diversity of the biophysical characteristics of wetlands and of the socioeconomic attributes of their surrounding environments and of users are determinants of the prevailing wetland use (types, intensity, and duration). The aims of the study are: (i) to capture wetland diversity in this multidimensional space; (ii) to classify and characterize assessment units in the wetlands based on their biophysical characteristics and socio-economic attributes using multivariate analysis methods; (iii) to link classification attributes to major land use types, deriving driving forces for use; and (iv) to provide an expert system able to classify further wetlands in the region.

Activities and key findings

Assessment strategies to determine the impact of land uses in wetland units: Data collected during an exploratory work in four localities in East Africa were analysed to evaluate the anthropogenic impact on different wetland units. Sampling localities comprised representative units of geo-morphology (valley bottoms and floodplains), to bio-climate (tropical Monsoon, tropical savannah and temperate bio-climate with dry winter and warm summer), to floristic region (Congolian, Somalian, and Zambesian), and to socio-economic attributes (demography, market access). We delineated and mapped assessment units in selected 250x250m tiles (polygons with homogenous vegetation cover and affected by similar land use type and intensity) and linked their attributes to the wider socio-economic environment.

The WET-health approach: This approach was selected as reference for assessing the anthropogenic disturbance of wetlands based on "WET-health scores" ranging from 0 (no impact) to 10 (complete loss of wetland properties). Their estimation occurred in four modules, namely hydrology, geomorphology, vegetation, and water quality. Trends and distribution of scores depended primarily on the assessment module, the land use and the flooding regime (Figure 3, Annex). All modules indicated a high diversity of the degree of disturbances and their impact. The approach was deemed suitable for a wider assessment of East African wetlands and has been published in a high-impact journal.

Additional variables for assessment: Beyond WET-health scores, a wide range of additional variables were collected from secondary data sources and through expert assessments and participatory stakeholders interviews. Such variables summarize different properties of assessment units, including type and intensity of use and social-economic attributes. The variables with highest indicator values included (1) the share of annual plants, (2) drainage intensity, (3) land use intensity, (4) soil tillage, (5) amount of inputs, (6) market access and commercialization, (7) vegetation cover and structure, and (8) the provision of ecosystem services. Data are summarized in two publications currently in preparation.
WP-A2: Potentials, uses, constraints

Abstract: Resource availability differs in space and time and determines the agricultural production potential. Assessing the actual and potential yields and quantifying the main limiting factors will guide intervention strategies and the assessment of wetlands’ future contributions to food security. We analyse rice and maize and vegetable production systems at the two super test sites and relate yields to resource base and management attributes using a yield gap approach. Additionally, post-harvest and other losses are evaluated along the value chain for selected commodities. The knowledge gained will guide future land use and management strategies.

Objectives: We defined two “super test sites” (lowland floodplain at Ifakara, Tanzania and a highland valley in Namulonge, Uganda) where all disciplines are active and contribute to knowledge generation. The sites were selected for their representativeness of major wetland systems based on the typology (WP-A1), and are characterized by available infrastructure and base line data. In central field experiments we establish resource inventories, assess technology options, and monitor their impact on the biophysical and social-economic environment over several years. At each site, three fenced observation and experimental areas of 2500 m² were established, covering in main hydrological and edaphic situations (moist fringe, seasonally dry mid-section, and year-round wet centre positions). At all sites and positions, we analyse production systems, technology options and yield gaps with the aim to link potentials, uses and constraints in a trans-disciplinary approach to available biophysical resources and household production factors.

Activities and key findings
A review of published literature of the last ten years about potential, uses and constraints of agricultural production in African wetlands and of biodiversity (both vegetation and animals) has been compiled. The on-going field research activities determine potential and actual yield levels and the main yield-limiting factors for diverse climatic and edaphic environments, and assess losses along value chains in the case of selected marketed commodities. The activities combine crop growth modelling with field experimentation and household economic surveys with the aims to establish yield resource use gaps of maize and rice, to quantify yield and yield-limiting factors, and (iv) to determine losses along value chains. In the agronomic experiments we compare three strategies: (1) In yield gap trials, we quantify the role of weeds, nutrients and supplementary irrigation on bridging the gap between actual and potential yields of dry season maize and wet season rice; (2) in intensification experiments, we compare extensive uses with single and double crop options on yields and on changes in resource base quality and ecosystem service provision; (3) in diversification trials, we study alternative agronomic management options comprising pre-rice and pre-maize green manures, post-rice forage legumes, and the use of farmyard manure und composts. Resource- as well as the management-related productivity gaps will later be combined with integrated social-ecological modelling approaches to guide the definition of social ecological niches for re-engineered spatial-temporal-organizational patterns (WP-D1).

Dynamics of resource availability: We quantify wetland use-induced changes C and N stocks and available soil nutrients in major wetland and land use systems of East-Africa, determine their relation to specific Eh- and pH-conditions and relate these to C- and N-fluxes between pedosphere and atmosphere. The first 240 soil samples were taken from the Uganda site from depths of 0-50 cm. We observed a large horizontal variability in Eh, EC and pH (Figure 5; Annex). The contents of OM, C_\text{tot}, N_\text{tot}, \text{Fe}_{\text{oxalate}}, \text{Fe}_{\text{dithionite}} gradually decrease vertically from the surface to a sandy layer at around 30-40 cm to increase or stabilize again at greater soil depth. (Figure 6, Annex). The analysis of the particulate-organic-matter (POM) fractions by density-fractionation is still on-going. The greenhouse gas fluxes differed between land uses, but also varied within the replicates of each treatment. Highest CO₂ and CH₄ fluxes were associated with periods when the redox potential at 10 cm depth increased, while largest N₂O fluxes occurred directly after soil tillage. Soil samples from the Tanzania site are still under analysis. Greenhouse gas fluxes from common wetland use scenarios are determined in weekly static-chamber measurements at the super test sites. Gas samples taken in the field are transferred for analysis to the laboratory. At the same time, soil samples are taken on a weekly basis to determine soil moisture, labile C and mineral N dynamics (analyzed in-situ). Bulk soil samples (monoliths) have been taken transferred to Germany for incubation / calibration experiments that will assess trace gas emission dynamics in relation to the hydric regime, SOC and N\text{min} under controlled conditions in a greenhouse in Bonn.

Crop management systems: A first assessment of cropping systems was carried out in the frame of the typology tour (WP-A1). In ongoing socio-economic survey, a more comprehensive questionnaire is administered to a large number of households (WP-A3) to further characterize the crop management systems in three of the four target countries. Dominant agricultural wetland uses comprise dry season maize (grown on 23% of the cultivated wetland area, n=103 households) and wet season rice (17% of the cultivated wetland area, n=76 households), irrespective of the position in the wetlands. Field vegetable cover 8% of the cultivated plots and are mainly concentrated in the wetland fringe positions. Rangeland (forage) uses are restricted to dry season grazing in floodplain wetlands. Assessments of yields, resource efficiency gaps, yield-limiting factors, and losses along value chains focus accordingly on rice, maize and vegetables.

We investigate production potentials and yield-limiting factors in rice and maize by combining field experiments (both on-farm and in the central experiments at the super test sites) with the use of calibrated and validated crop models
Activities on post-harvest losses focus on rice and maize. A site-specific evaluation of the APHLIS (African post-harvest losses information system) indicates considerable losses for the main staple crops. In Kenya, post-harvest losses of maize reached up to 27%, corresponding to an absolute loss of 323,558 t. These losses could be ascribed mainly to poor on-farm storage (grain borer damage). In the other target countries, losses were less with 17% in Uganda, 18% in Tanzania and 23% in Rwanda.

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In the peri-urban fringes of Kampala, Uganda, vast areas of land are bought by real estate firms and are resold as plots to the upcoming middle class. The conversion into housing estates hampers the access of smallholders, making leaseholds scarce, and increasing the pressure on remaining wetlands. Eemic perceptions of malaria risks and local knowledge of remedies in relation to wetlands and their use, as well as smallholders’ access to the health care system have been researched during nine months of ethnographic fieldwork in 2015. The health care system can be divided into three sectors, (1) the professional, (2) folk, and (3) popular sector, in which health care is activated, carried out and evaluated. Discrepancies between local and biomedical understandings of typical wetland-related health risks such as malaria as well as a popularization of biomedical health terminology and practices can be observed. The understanding.

**WP-A3: Socio-economic evaluation**

**Abstract:** The diversity of and the benefits accrued from agricultural uses of wetlands (WP-A2) require an understanding of the social, economic and cultural factors that shape patterns of access to and use of wetlands, and an evaluation of crop management systems’ contribution to livelihood. In collaboration with “public health” and “social geography”, the socio-economics group analyzes dynamic land use patterns and scrutinizes how health issues impact them. Research also addresses gender relations regarding wetland access, as well as land use and benefit.

**Objectives:** To contribute to the socio-economic dimension of wetland uses, we determine the social, cultural and economic backgrounds of users, explore their management systems, and investigate the health risks associated with wetland uses. Gender aspects receive special attention in analyzing the factors that govern women’s involvement in the use of wetlands. Furthermore, the role of both formal and informal institutions in governing access to and use of wetlands is determined.

**Activities and key findings**

In joined activities by the social anthropology, the economics and the public health groups, we assess the social-cultural and economic dimensions of wetland uses. Anthology and Public Health focus on wetland users in Uganda, Rwanda and Tanzania, aiming to provide information about user groups and their practices related to the wetlands, but also to provide an eemic perspective on how farmers, workers or residents perceive wetlands related risks and opportunities. Activities assess institutional dynamics governing organization, access, ownership and use of wetlands, gender relations and women's participation in wetland-related activities, and the political ecology of health in wetland areas and of wetland users. The economics group administered survey questionnaires, collecting data on household characteristics, land use, production systems and other socio-economic variables (see also WP-B3) to provide the economic dimension of wetland use. Findings from 2 years field research indicate a weak implementation of government-rules at the local level, rendering official wetland policies ineffective. This varies between countries, different wetlands within a country, and in time. Generally agricultural production (both crop and rangeland uses) but also land speculations result in the collision of interests among political institutions and increase conflicts between wetland users and with other stakeholders.

**Uganda.** In the peri-urban fringes of Kampala, Uganda, vast areas of land are bought by real estate firms and are resold as plots to the upcoming middle class. The conversion into housing estates hampers the access of smallholders, making leaseholds scarce, and increasing the pressure on remaining wetlands. Eemic perceptions of malaria risks and local knowledge of remedies in relation to wetlands and their use, as well as smallholders’ access to the health care system have been researched during nine months of ethnographic fieldwork in 2015. The health care system can be divided into three sectors, (1) the professional, (2) folk, and (3) popular sector, in which health care is activated, carried out and evaluated. Discrepancies between local and biomedical understandings of typical wetland-related health risks such as malaria as well as a popularization of biomedical health terminology and practices can be observed. The understanding.
of health in relation to wetland agriculture is narrowly linked to the socioeconomic and political factors that influence the way in which local stakeholders access and make use of wetlands and their resources. Economic resources are a determining factor for the health-seeking behavior of local farmers, especially when looking at malaria. In the densely populated fringes of Kampala, wetlands thus play an important role in the health-seeking behavior of local smallholders, as they are increasingly valued as a source of income.

**Tanzania.** Despite the favorable policy and legal frameworks, which encourage women's rights, only few women own land in wetlands. Most of them only have access to family land and cannot inherit land, reflecting the persistence of gender inequality in land access and ownership, which is primarily hinged on customs and traditions. Limited economic power aggravates the situation of women, with negative consequences on production and family well-being. While the quantity of rice produced by small-holder farmers increased only marginally between 1991 and 2010, mainly as a result of area expansion, it has increased significantly since 2011 as a result of land use intensification. This corresponds with a system of reorganizing small-holders into farming groups through which knowledge and inputs are passed, and market networks sought, resulting in reduced transaction costs. The longer-term benefits and the sustainability of such intensification strategies are currently being assessed. Finally, recent tensions between farming communities and pastoralist groups in the Kilombero floodplain have been reduced by laws (i.e., forceful removal of pastoralists from many parts of the district in 2012). However, high numbers of these formerly resettled pastoralists (Sukuma, Maasai and Barbaigs) resurfaced in 2015, leading to renewed tensions, particularly in the main rice-growing districts. However, conflicts over wetland use also increasingly arise in the 14.700 km² (50% of the floodplain) that are gazetted as protected area (KVFP Ramsar site and Kilombero Game Control Area). Here, traditional semi-nomadic pastoralists and small-scale agro-pastoralists increasingly compete for land with large-scale crop producers (usually wealthy absentee farmers) who buy land from agriculturists who are abandoning farming because of shocks.

**Rwanda.** In the past two decades, Rwanda has undergone many transformations. It was the first East African country to declare wetlands as state property and effectively placing them under governmental control. Since a decade, wetland access is organized into larger entities through cooperatives, which must be recognized on the national level. These cooperatives serve as a political tool to improve the implementation and control of wetland policies, and limit the rightful access to wetlands. While vulnerable groups are encouraged to enter these cooperatives, performance pressure and a neoliberal market environment in many cases undermine the cooperative's social functions. Thus, farmers who cannot afford cooperative membership fees or do not have the capacity to engage in the prescribed large scale production mode are gradually excluded. Many among them are female-headed households, which get excluded from privileges such as access to the more fertile wetland soil, counteracting the national reconciliation process by creating new forms of exclusion and inequality. Also at the household level, care-related activities largely remain in the responsibility of women, causing a double burden for them. However, from the economic perspective, wetland agriculture contributes substantially to household income and welfare, and the intensified wetland crop uses are largely responsible for the recent increases in the food security index from 27.3 in 2000 to 35.3 in 2015). The cross-country comparative analysis of economic data will be the focus of activities in 2016 and will thus link agronomic activities (WP-A1 and WP-B1) and ecosystem services (WP-A4), providing the basis for the transdisciplinary definition of social-ecological niches (WP-D1).

### WP-A4: Ecosystem services

**Abstract:** Planning the use of wetlands for food production while maintaining other critical functions that wetlands fulfill requires a comprehensive overview of the diverse ecosystem services wetlands provide to various users. Key services include the provision of water and regulation of water flows, and biodiversity. Based on biophysical and socio-economic field surveys, remote sensing and stakeholder workshops, we assess critical ecosystem services. Besides species inventories, indicator values and traditional uses, environmental economic accounting and welfare-based approaches are applied to valuate wetland-derived ecosystem services.

**Objectives:** This work package develops a (sub-)national assessment methodology for identifying critical ecosystem services supplied by wetlands, and possible trade-offs related to wetlands’ conversion to sites of production. We conduct cross-sectional inventories of plant and animal biodiversity in wetlands undergoing use changes, identify critical indicator organisms, and assess the importance of diverse services and their contribution to welfare of individuals and communities in Kenya, Uganda and Tanzania. An economic assessment methodology is being developed and applied to national case studies in Uganda and Tanzania.

**Activities and key findings**

Wetlands provide ecosystem services at different scales, ranging from the provision of products for local users, over the regulation of water flows at the intermediate level, to global services such as C sequestration. The extent of these services differs by environment and wetland type, and their vulnerability to anthropogenic interventions (here primarily wetland conversion into sites of agricultural production) is critical for the well-being of wetland-related communities. Extensive literature surveys have been conducted with special focus on wetland biodiversity and on the valuation of wetland ecosystem services. Species inventories were compiled and structured in data bases. Vegetation has been
Animal biodiversity. Beside the vegetation and plant species diversity, the distribution, abundance and dynamics of recorded species are identified. Finally, economic frameworks for analyzing benefits and trade-offs have been established.

Plant biodiversity. The cross sectional inventories of wetland plant biodiversity (both taxa and vegetation formations) are stored in the SWEA-Dataveg (Figure 7, Annex). By December 2015, the database has increased to includes entries on > 2,400 species collected from < 3,000 plots in the four target countries (Figure 8, Annex) as well as in Togo, the Democratic Republic of the Congo and Benin (http://www.givd.info/ID/AF-00-006). In the central field experiments in Uganda and Tanzania, we monitor the dynamics of vegetation regeneration after various degrees of anthropogenic disturbance. The sites differ strongly both in terms of seasonality of vegetation growth as well as in the dynamics of species abundances and composition. In the valley in Uganda, annual species are gradually replaced by perennials and during the dry season in the wetter center position of the floodplain. We propose to use such regeneration dynamics together with attributes such as cover, height, and share of annual species to predict the vulnerability of wetland to anthropogenic disturbances (Figure 9, Annex). The collected data support further wetland classification activities. We thus classified aquatic and semi-aquatic wetland vegetation into five major phyto-sociological classes, representing communities of submerged and rooted floating plants (Potametee), communities of free floating plants (Lemnetee minoris), marshes and reeds (Phragmite-Magno-Caricetea), weed communities of rice paddies (Oryzette sativae), and edaphic grasslands (Hyparrhenietee). By means of a supervised method, classification algorithms are implemented in an expert system, allowing extending vegetation classification also to terrestrial environments (Figure 10, Annex). The biodiversity database is also used to share analysis routines. Thus, in 2015, the SWEA-Dataveg was used to calculate diversity models and apply the results in environmental economic studies in collaboration with the ETH in Zurich. Relating patterns of alpha and beta diversity to estimated costs for nature protection measures, suggests the desirability and economic feasibility of a substantial expansion of protected wetland areas (Scherer et al., 2015). Finally the database will be used to extract relevant information on representative species to be included in a Wetland Vegetation guide book planned for 2016.

Animal biodiversity. Beside the vegetation and plant species diversity, the distribution, abundance and dynamics of animals are assessed along biophysical and disturbance gradients in Uganda and Kenya. The work on vertebrates focusses on herpetiles (reptiles and amphibians) and small mammals (rodents and shrews) in three major land use types around the test site in Uganda (Papyrus swamps, forested wetlands, cultivated wetlands). Herpetofauna surveys were conducted using visual encounter survey method. A total of 21 amphibian species belonging to 9 genera and 7 families were recorded in 2015, all belonging to the order Anura. The family Hyperoliidae showed highest diversity with significant differences in species composition between the 3 habitat types. A total of 17 reptile species belonging to 11 genera were recorded with 6 genera in the order Sauria, contributing >86% of encountered individuals. Some 15 small mammal species belonging to 10 genera and 2 families were sampled. The family Muridae was most diverse (11 species in 8 genera), however, no relationship of species composition or abundance with land use was apparent. With species diversity differing significantly among habitats, herpetiles (in contrast to mammals) appear to be suitable indicators for wetland disturbance. All sampled specimen samples have been fixed in formalin and preserved in 40% ethanol, and are conserved and available for further reference at the Makerere University Museum in Kampala. In Kenya, the diversity and spatial-temporal dynamics of both above and belowground invertebrates is assessed along transects (gradients of anthropogenic disturbance) around the Ewaso-Narok floodplain based on 10x10m sampling plots, we quantify in regular intervals the presence and abundance of bees, dragonflies, and butterflies (sweep netting), beetles and arachnids (pitfall traps), and nematodes and collembolans (Berlese). Data on invertebrates are related to the degree of anthropogenic disturbance, to prevailing vegetation forms and plant species and to soil and water physico-chemical attributes or changes. To date 16 orders from 79 families of invertebrates were recorded in two sampling seasons. Most abundant are Coleoptera, Hymenoptera, Hemiptera and Diptera. Within the butterflies, 217 individuals, comprising 42 species from 5 families have been identified, with diversity and distribution varying seasonally. Their abundance and distribution appears to be strongly related to anthropogenic disturbance, suggesting their use as indicator species. A reference collection of all taxa collected is developed and will be available at the National Museums of Kenya (Figure 11, Annex.

Valuation of ecosystem services: Surveys on traditional uses of plants and animals by wetland communities, and on perceived benefits and risks are being conducted to in Kenya and Uganda in view of linking biodiversity to provisioning ecosystem services and contributing to studies on ecosystem services. The valuations of ecosystem services provided by wetlands and potential economic impacts or trade-offs associated with their loss have started in Uganda and Tanzania in 2015. A framework for analysing and valuing ecosystem services has been drafted. Spatial data were compiled in collaboration with WP-D3. A survey questionnaire has been developed, complementing the more general household survey implemented by WP-B3. Field data collection on household activities in wetlands has started. Combined with spatial data and household surveys, the framework will allow a structured analysis of ecosystem services at both sites. First results on the social and the economic valuation of ecosystem services are expected by 2016.
WP-A5: Water and matter fluxes (functioning of wetlands)

Abstract: The availability of water at wetland and watershed scale determines soil quality parameters and the production potential for crops and forages at plot scale. The dynamics of ground and surface water fluxes is studied regarding their effects on the spatial-temporal availability and the transformation of carbon and nutrients and water-associated human health risks. Process studies are combined with modelling approaches to understand the functioning of wetland systems.

Objectives: Wetland attributes (types, vegetation, soils), production potential and health risks, and ecosystem services are largely determined by the spatial-temporal dynamics of ground- and surface water and soil moisture. This work-package determines the wetland-specific variability of solid and solution soil phase parameters as well as the related gas fluxes. It determines the variability of water quality, and evaluates water quality with respect to human consumption and food production, and quantifies the proportion of groundwater within the wetland system. The aims are to quantitatively assess: (i) the dynamics of resource availability, (ii) the dynamics of groundwater, (iii) water quality and public health, and (iv) water balance on wetland and catchment scale.

Activities and key findings

Water dynamics and quality. The measurement of groundwater levels revealed major flow paths. Snapshot samplings of groundwater, stream water, flood water, and soil moisture, including the measurement of trace elements and stable water isotopes were carried out in 2015. Geological mappings, drilling surveys and the determination of hydraulic properties allowed establishing detailed geological and hydrogeological maps and developing hydrogeological models (Figure 12, Annex). These models are now used as visualization tools for stakeholders to understand linkages between agricultural uses and groundwater. The two super test sites show completely different hydrogeological settings, while they conform in some major flow processes. In Ifakara, groundwater flows through an unconfined aquifer and discharges to the river. In Namulonge, groundwater flows in a deeply weathered bedrock aquifer, while local groundwater below the wetland occurs in a confined alluvial aquifer of the valley bottom. Both wetlands were identified as discharge areas, indicating that groundwater contributes to wetland water, both in terms of quality and quantity. A PhreeqC model quantified mixing ratios between different water compartments and hydro-chemical processes within the compartments. The major process controlling groundwater chemistry in both test sites is silicate weathering accompanied by cation exchange. Additional measurements of water quality indicators showed that water quality for human consumption and agricultural production is good in Namulonge, while hotspots of anthropogenic contaminations (mainly NO\textsubscript{3}) were identified in Ifakara. Information sheets on water quality were established and distributed to water users in 2015. The hydrological monitoring at Namulonge indicates that 69% of the surface water entering the wetland is being retained and the wetland acts as a sediment trap. Interactions between stream and shallow ground water flow are observed for the entire Namulonge wetland while the second deeper aquifer is disconnected from the river. At Ifakara, piezometers equipped with loggers, automatic soil water stations, FDR sensors and mobile moisture profile access tubes have been installed to understand the hydrological processes at plot scale. In addition, the one-dimensional finite element model HYDRUS 1D was successfully applied to simulate alternate drying and wetting of the soil profile, relevant for both trace gas emissions and crop production potential. Finally, a grid-based SWAT model was applied based on a 30 m resolution SRTM digital elevation model, a detailed soil map, and a land use map derived from a SENTINEL2 classification. Due to the large size of floodplains (Ifakara in Tanzania and Ewaso-Narok in Kenya), a review on global geo-datasets has been conducted to assess water balances at catchment scale. A field study in the Ewaso-Narok has generated an inventory of precipitation, discharge, and water abstractions. This data are being used to calibrate and validate the SWAT model for Ewaso Narok. Discharge data from the Rufiji Basin Water Office in Tanzania a water balance analysis has also been conducted for the Kilombero catchment. However, a temporal mismatch between the spatial representation of discharge and precipitation measurements limits an adequate simulation of hydrological processes. While the hydrological model is available, its calibration and validation will require further data. In this context, discharge and bathymetrical measurements for flood simulation modelling are under way.

Resource fluxes. These water and soil moisture dynamics and water balances influence soil attributes and trace gas emissions. All major soil profiles at the super test sites in Uganda and Tanzania have been characterized and redox potential, water soil moisture availability and quality, and trace gas emissions are continuously monitored in contrasting land use treatments. Gas fluxes show strong seasonal dynamics and differ between wetland types and wetland among position. Largest methane fluxes were observed from center position of the floodplain under intensive rice cultivation while largest N\textsubscript{2}O fluxes occurred in the valley fringes during the dry-to-wet season transition period. These latter fluxes are related to seasonal dynamics of in-situ soil N mineralization and a 20-40% nitrate-N contribution by subsurface flow from the adjacent valley slopes. The role of slope attributes on the spatial-temporal soil water and nitrate dynamics in inland valleys and hence on trace gas emissions is currently being studied at catchment scale in Uganda. Eventually, these data on resource availability and resource base quality (water and moisture dynamics, soil attribute changes and gas emissions) will be used as input parameters in crop growth simulation models to assess wetlands, catchment and regional agricultural production potentials.
3.2 Cluster B: Alternative options for wetland use

Wetlands are and will increasingly be converted for agricultural production to meet growing food challenges. The aim of wetland use must be meeting future food production needs without jeopardizing the wetlands’ ability to provide other essential ecosystem services. Such “wise” uses of wetlands are likely to differ by wetland type (WP-A1) and production potential (WP-A2), and their adoption will be driven by social-economic conditions in the communities surrounding the wetland (WP-A3) and the role and value of other ecosystems services (WP-A4). Finally, technology options, benefits derived from them, or associated trade-offs will depend on resource availability and resource base quality (WP-A5). Developing improved production methods increasing yields while not compromising the environment or human health is the key challenge of Cluster B. Economic profitability, cultural acceptance and feasibility play decisive roles for successfully implementing agronomic innovations. Production and productivity increases can be realized by closing the yield gaps for key commodities or by introducing new systems. Integrated approaches pursued include the use of biological nitrogen fixation, the synchronization of nutrient supply with crop demand, and the reduction of postharvest losses. Conserving biodiversity and enhancing ecosystem services are key factors for long-term sustainable wetland uses. Besides the performance attributes of the technical options (WP-B1), we therefore evaluate also technology effects on on-farm biodiversity, resource base quality (C and N pool changes) and other ecosystem services (WP-B2), and assess economic benefits and production factor requirements for key technologies (WP-B3). The impacts of technology options on production, ecosystem services and economic benefits or requirements are integrated into a trans-disciplinary modelling framework, enabling the formulation of recommendations about “wise” uses of wetlands (WP-C3).

WP-B1: Testing and modelling alternative management options

**Abstract:** This WP develops adapted or “wise” land use options, thus providing the inputs for the decision toolbox developed in WP-C3. The proposed strategies comprise “extensification vs. intensification”, “conservation vs. intervention”, and “organic vs. mineral” strategies, and are based on the wetland typology (WP-A1), the yield gap surveys (WP-A2) and on nutrient balances (WP-A5). Agronomic management and “eco-intensification” options are evaluated in representative wetland environments using field experimentation and simulation modelling. Physical and biological approaches to reduce losses and conserve product quality are comparatively assessed during harvest storage and transport. Technology effects on production and resource base quality are compiled for use in the modelling framework.

**Objectives:** The main aims are (1) testing intensification and diversification options for rice- and maize-based and for selected vegetable-growing systems; (ii) assess their impact on ecosystem service provision, and (iii) model alternative technical options. Activities are largely based on researcher-managed field trials, established at the fringe, middle and center positions at the two super test sites in Uganda and Tanzania. We quantify yield gaps and key yield-limiting factors, compare crop intensification (double cropping, external input use) and diversification strategies (off-season food, green manure and forage crops), evaluate technology effects yield, productivity and resource base quality for key technologies.

**Activities and key findings**

Studies on lowland rice and maize were conducted in Uganda (valley swamp) and Tanzania (floodplain). Yield gaps differed by site, crop, and position, and technology options differentially affected yields by wetland environment (floodplain vs. valley swamp), by position in the wetland (fringe, middle, center) and by season (dry vs. rainy season). Yield gaps (differences between potential and actual yields) were generally large and tended to be more in the floodplain than in the valley swamp. Main yield-reducing factors (water, weeds, nitrogen), on the other hand were the same across environments, but differed by position in the wetland. Selected findings from the Uganda case study in the 2015 wet season show that relatively high yields can be obtained from the wetland (mean of about 5 Mg ha\(^{-1}\)), with significant differences between treatments, but no interactions between fertility management and hydrological zone. Highest rice yields of 7.4 Mg ha\(^{-1}\) were obtained in the intensification treatments with high external input use (120 kg N ha\(^{-1}\)), while farmers’ management (no bunding, one manual weeding) resulted in only 2-3 Mg ha\(^{-1}\). The application of organic amendments (green manure or farmyard manure) provided no significant yield increase, irrespective of the plots' position in the wetland. However, mean grain yields were always higher in the valley fringe (5.3 Mg ha\(^{-1}\)) than in the middle or center positions (4.6 Mg ha\(^{-1}\)). Grain yields in the subsequent short rainy season were 35% lower than in the main rainy season, particularly in the fringe positions (maximum grain yields of 4.8 Mg ha\(^{-1}\)). However, organic amendments tended to increase grain yields and biomass production at flowering was highest in organic treatments (8.46 Mg ha\(^{-1}\)). In Tanzania, excessive rainfalls and severe flooding lead to complete crop failure in the center position of the floodplain in Tanzania. In the fringe and middle positions fertility management effects were very pronounced, however the mean yields of 4.1 Mg ha\(^{-1}\) were much lower than in Uganda, despite higher solar radiation and consequently higher potential (simulated) grain yields in Tanzania. This is related to much lower fertility of the Fluvisol in the floodplain than of the Gleysol in the valley. However, also in the floodplain, organic amendments provided only slight benefits with green manure (Lablab purpureus) clearly out-yielding the farmyard manure. Crop diversification by off-season cropping (maize and cowpea) was restricted to the moist center position of the floodplain. The maize trials were carried out during the dry season in early 2015. In contrast to the rice trials, the position effects turned out to be the main factor for maize
productivity. Total biomass was the highest in the center (10.4 Mg ha\(^{-1}\)) and lowest in the fringe positions (4.8 Mg ha\(^{-1}\)). In analogy, grain yields reached 4.9 Mg ha\(^{-1}\) in the center and only 1.4 Mg ha\(^{-1}\) in the fringe. Yield response to applied mineral or organic N was relatively low (22%). Largest effects (nearly 30% increase) were observed with green manure (Sesbania rostrata). The findings support the need for environmental-, site- and position-specific technical solutions.

**WP-B2: Environmental effects of alternative options**

**Abstract:** Practices associated with agricultural wetland uses include soil drainage, tillage, and input uses that differentially affect resource availability and resource base quality. The environmental impact of alternative management options is being quantified, including changes in hydrological processes, groundwater availability and water quality, soil C and N stocks and seasonal nutrient fluxes, and soil trace gas emissions. The results are used for model calibration and validation and will be fed into the central database as a basis for defining social-ecological niche environments (WP-D1), up-scaling (WP-D3) and policy recommendations (WP-D5).

**Objectives:** The environmental impacts of different intensification and diversification use options on resource base quality changes is quantified in terms of hydrological and hydrogeological processes, water quality, soil C and N content, and nutrient and gas fluxes. The following specific aim are pursued: (i) assess the impact of management options on on-farm biodiversity; (ii) model cropping intensity effects on hydrological processes and water-related ecosystem services, (iii) determine effect of management options on water quality and public health, (iv) quantify changes in C and N stocks and soil nutrient status with different intensification and diversification strategies; and (v) quantify trace gas fluxes under different wetland use scenarios.

**Activities and key findings**

Vegetation inventories, major species associated with crops or following phases of cultivation and general vegetation dynamics under extensive, intensive and diversified land uses has been compiled in Uganda and Tanzania. Hydro-chemical samplings of soil water assess the effects of management options on water quality. The instrumentation of the valley in Namulonge, Uganda has been completed in 2015. Comparable installations are not possible in the floodplain of Ifakara where hydro-chemical modelling is used instead. Along hydrological transects soil physical data were collected and a map of soil physical properties of the Kilombero floodplain has been developed, applying the geospatial kriging interpolation methods. The characterization of major soil profiles under contrasting land use and management and sampling for \(N_{\text{min}}\) dynamics was also carried out in Tanzania in 2015. In Kenya (Ewaso Narok floodplain), the anthropogenic impact of land management on soil physical properties and on soil water dynamic is under analysis. Contents of soil nutrients and C/N ratios were analyzed twice during the cropping season in each plot of the central experiments. The bi-weekly sampling of greenhouse gases that started simultaneously with the onset of the cropping seasons in 2015 in both Uganda and Tanzania. Wetland management differentially affects wetland vegetation associated with crops, soil physical properties, soil moisture availability, and shallow groundwater/surface water dynamics at wetland scale, and hence some of the major provisioning and regulating ecosystem services. Soil moisture retention is generally higher in bunded rice than in non-bunded plots and increases from fringe to center positions. Large differences in the spatial dynamics of soil organic C and bulk densities appear to be determined by both the hydrological regimes (position, field bunding) and land uses (cropping intensity and diversity). The nutrient dynamics studies show more \(N_{\text{min}}\) in valley bottom than in flood plain soils. Despite substantial \(N\) inputs from adjacent slopes during the dry-to-wet season transition soil \(N_{\text{min}}\) contents in valleys are generally low during the wet season and less in rice than in maize. Emission studies support these trends, showing strong seasonal gas flux dynamics. Methane emissions were generally less in maize than in rice, and \(N_2O\) fluxes were highest in fringe positions, irrespective of the crop. This suggests substantial \(N\) losses by denitrification, particularly at the fringe positions and at the end of the transition season. Such soil \(N_{\text{min}}\) dynamics and associated \(N\) losses appear to be more with intensification treatments (year-round cultivation, high external inputs), but tend to be less with crop diversification (off-season cropping, pre-rice green manure, post-rice forage crops). Preliminary findings also suggest that moderate intensification at wetland fringe positions (building of field bunds) and crop diversification at wetland centre positions may positively influence hydrological and edaphic attributes and associated ecosystem services. Hence, alternative land use options are likely to differentially affect the provision of other ecosystem services, depending on wetland type, main crop and position within the wetland.

**WP-B3: Economic analysis of alternative (wet-)land use options**

**Abstract:** We assess alternative in comparison with current land use options under specific economic and institutional conditions. Farm-household models with an explicit representation of agricultural technology in bio-economic sub-modules are specified. The modelling approach shall employ behavioural assumptions for the main users and take into account relevant institutional constraints and interactions, including the market environment. The economic assessment of management options will yield site-specific recommendations and quantify their effects on the actors involved.
**Objectives:** Overall, the work package provides the economic assessment of alternative wetland uses. We develop a spatially-explicit Agent-Based Model to evaluate the reaction of heterogeneous agents to different socio-economic, management and change scenarios, and assess their impact on land use change. We assess alternative land use option in comparison with current land use under differing natural, economic and institutional conditions. Activities aim to (i) identify relevant agents and conceptualize behavioural models; (ii) implement behavioural models for agents and calibrate the status quo; and (iii) assess alternative management options in model formulation and scenario analysis, reflecting the resource endowment of farmers and production factor requirements of specific technical options.

**Activities and key findings**

An extensive review of literature on agent based models was completed in 2015. Using a Conceptual Design framework, different agent based models were reviewed with the objective to identify processes commonly implemented (both the physical and social) and explaining land use changes and assess the proposed wetland use technologies (WP-B1). In contrast to most available models, the one selected and proposed here will be able to incorporate relevant bio-physical processes and wetland use dynamics. System conceptualization of Agent-based modeling began with defining agents (both individuals and groups), their behaviors and roles, and interactions between them and with the ecological system. The ecological components are wetland resources representing geographical spaces at the catchment level that the agents perceive and interact upon.

In 2015, comprehensive, detailed and geo-referenced socioeconomic survey household surveys were completed, aiming at collecting socio-economic and demographic data from diverse wetland users. Some 1053 wetland users (farmers, agro-pastoralists, pastoralists, artisans and conservationists) had been interviewed in Kenya, Uganda and Tanzania. Data entry will be completed in 2016. The analytical framework for econometric analysis of the drivers of agricultural intensification within East African wetlands was developed. A modified production function taking into consideration the asymmetric influence of growth and facilitating factors on crop output is being used to assess the influence of policy, market and population related factors of crop production strategies within wetlands of the research areas (Figure 13, Annex). Further, Stochastic Frontier Analysis will be used to estimate the technical and allocative efficiency among wetland producers and assess the efficiency of crop production within wetlands. The determinants of technical efficiency have been established as a step towards identifying policy options for enhancing sustainable food production under different wetland use scenarios. Additionally, expert interviews with district officials and private investors were performed in the Kilombero floodplain, targeted at identifying the socio-economic dynamics of the system. The survey data was collected in 22 villages where 304 randomly selected households were interviewed. This survey is being used to reflect on our understanding of decision-making behavior among wetland users and a set of decision heuristics based on informant responses. In, general five distinctively different types of agents emerge among the wetland users, each representing their own and in parts conflicting interests: Farm households, agro-pastoralists, pastoralists, private investors and district land use planner. In addition to a shared wetland landscape, land, labor and output markets, social networks, and formal and informal rules that govern the use of wetlands are the main institutions where horizontal or vertical interaction of these agents occurs. Farmers comprise the largest group of agents, who differ in ethnicity, social and economic status. Rice is the traditional food crop in the area, and maize and cassava are other common subsistence crops produced by farmers. Households also grow a variety of fruits and vegetables for their own consumption. Due to poor infrastructure, and limited access to transport and information, most farmers are restricted to their local markets. Much of their produce is bought by middle-men who offer a low price and sell in larger urban markets at higher prices. Farmers are unlikely to invoke frequent changes in their decision-making behavior or do things that are dissimilar to each other when it comes to crop choices. Interviewees indicated that they have been making the same crop choices and for similar reasoning in the past five years. Higher productivity and the fact that plots are unsuited for other crops are the main reason (Figure 14, Annex ). Further exploring different, less explicit drivers of decision-making and decision heuristics and the conceptualization of the dynamic land use model are in progress..

### 3.4 Cluster C: Integration and Scenarios

Comprehensive information about biophysical and socio-economic attributes of different wetland types, their key eco-physiological functions, management in distinctive socio-economic settings, ecosystem services, and potential for agricultural production are collected, stored and centrally managed in the data base facility. Data are gathered by the inter-linked projects of cluster A, all of which are aimed at understanding the functioning of wetlands from different disciplinary points of views. Options for improved or alternative crop management and their environmental and socio-economic effects are assessed in cluster B based on insights gained from cluster A. Transforming knowledge of these different information sources into models for scenario calculations and regional up-scaling requires the application of trans-disciplinary systems analysis. Relations between functional aspects of systems are commonly established at a high level of abstraction using statistical and mathematical modelling techniques, and then interlinked using model-based reasoning and scaling. The resulting integrated social-ecological model is simpler than the original sub-model formulations, permitting the subsequent process of scenario analysis, which forms the basis for policy recommendations and practical decision making. Three interlinked workpackage include (i) the provision of a spatially-explicit database infrastructure for collaborative research; (ii) assessment of global change scenarios; and (iii) the development of a coupled social-ecological wetland model for regional up-scaling.

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Abstract: This work package provides a geodatabase infrastructure, data management tools for different users, and a web-interface for scenario analyses needed for policy advice and decision support. It maintains consistency between various data sources and assures technical and semantic inter-operability. The database and tools are developed at the GIS centre of Makerere University, Uganda, and are mirrored in all participating countries for rapid data processing. The repository is accessible by different user groups.

Objectives: (i) Operationalization and management of geodatabase; (ii) Interfaces for models and clients; and (iii) Evaluation of a digital terrain models (DTMs) for super test sites.

Activities and key findings:

The data infrastructure model was improved based on information obtained from delivered data sets by the workpackages. Structured data (logger files and associated metadata) are stored in a relational database, while largely unstructured data sets from field research are handled by a NoSQL database formalism. A user-friendly web application based on the WISE concept was designed for easy data access. Maintenance of the geos- and address- databases require constant adaptations of data collection tools as well as entity relation and metadata models. Establishing the database on the server of Makarere University turned out to be impossible due to its poor reliability, low bandwidth, missing power backups, frequent electricity cuts, and unprofessional maintenance, and had hence to be abandoned. Instead, a commercial Strato server in Germany is used as an intermediate solution until a reliable server has been identified in Africa. The collected data sets have been transferred to this German server. Interfaces for data exchanges between the server and notebook-based virtual machines have been established. Synchronization times of the database are permissible even at the commercially available phone-network bandwidth in Uganda. The database mirroring with the Wetland server in Bonn we will institutionalize as soon as a reliable server solution is identified in one of the African partner institutions. Negotiations to this avail are currently on-going NACRII. A virtual machine and project management software was installed on the server in Bonn to support the development of the wetland model (C3). The Drupal implementation of the address database had to be improved to assure a one-to-one mapping between Drupal and the PostgreSQL database. A wiki was installed for documentation and team communication. An Ugandan student was enrolled and evaluates spatial resolution effects of different digital Terrain Models on hydrologic model outputs. Following data sources were analyzed: 1-m LiDAR, 5-m RTK, 30-m SRTM, 90-m SRTM, 250-m GMTED and 1000-m GMTED. First results indicate that errors in hydrologic flow modelling increases with reduced spatial resolution. We hence will apply high resolution models in the future to minimize uncertainties in flow calculations. A virtual machine was installed to cope with the demand of the resulting computing and storage demands. Tree density and height distributions have strong effects on the hydrological regimes of wetland catchments. Spatial distributions of trees and estimations of tree heights within the floodplain in Tanzania are investigated by a Tanzanian MSc student using photogrammetry and applying relative height modeling. We classify a binary tree/no-tree map, generate accurate digital surface models in a photogrammetric workflow, evaluate the accuracies of various 3D models, and assess the capability of the relative height model in determining tree height measurements. The deliverables from this research will be a very high resolution Digital Terrain Model (DTM) derived from UAV imagery and a Digital Surface Model (DSM) depicting tree heights in the study area. This information is required to calculate DEM-driven surface element fluxes and it improves our understanding of land conversion processes.

WP-C2: Global and regional change change scenarios

Abstract: The “Wetlands” project contributes to the understanding of the diversity and functioning of wetland systems, assesses alternative technical use options and develops decision tools for “wise” uses. Their implementation and the actual futures of wetlands, however, are uncertain, and depend on the economic development in the target countries, on the level of organization and implementation of regulations, and on climate change. We develop in a transdisciplinary process qualitative storylines and associated drivers of scenarios of change at regional, catchment and wetland scales. In addition, the climate variability is quantified and future global climate scenarios are downscaled to the wetland scale.

Objectives: The objectives include: (i) the generation of qualitative storylines and the quantification of drivers for two global change scenarios; (ii) the quantification of past climate variability and its causes; and (iii) a projection of regional climate change scenarios.

Activities and key findings

Scenarios and storylines: The hypothesis of the project is that in future wetlands will become the food basket of the region. Soil degradation, water deficiencies, and population growth lead to food insecurity. A more intensive use of wetlands is likely to reduce ecosystem services. Climate change will alter the hydrological and agricultural production conditions. Therefore, scenarios of the potential future development of wetlands are needed. A road map and methodical approach to construct scenarios and storylines was initiated during scenario development meetings. At the “plant 2030”
conference in Potsdam in 2015, partners discussed likely future developments in a “brain-storming” approach with a subsequent visualization and categorization in a “mind-mapping” exercise. Wetland governance structures and their implementation and major positive, as well as negative change processes (climate, policy, markets, demography, innovations, education, health concerns, conflicts, infrastructure, services, etc.), entail both risks and opportunities, and were identified as key determinants of likely future developments. In the follow up, the scenario development group generated four prototypes of future wetland developments: “Bricks”, “Tomatoes”, “Rice” and “Papyrus” (Figure 16, Annex). Impact studies within the second project phase can be evaluated via these final stages of future developments. The prototype “Bricks” refers to unregulated wetlands with predominantly negative change processes (risks) that are typically associated with destructive land use forms such as brick-making. The final stage “Papyrus” refers to regulated wetland access and use and positive or conservation-conducive change processes (opportunities), typically associated with wetland protection or sustainable uses that do not interfere in the wetland’s hydrology. The future prototype “Tomatoes” is synonymous to an intensified use of wetlands with a focus on short term profit while the prototype “Rice” stands for an intensified but sustainable use of wetlands. Finally, we assume that the “economic development” and “level of organization” will significantly impact the future developments of wetlands. On one hand, economy is assumed to be develop either strongly or weakly and on the other hand, a low or high level of organization is assumed to influence wetland developments (Figure 17, Annex). The use of wetlands can be regulated, unregulated, controlled or uncontrolled. The management of resources like water, nutrients and carbon can be proactive or reactive and health care can include curative and preventive aspects. As a result of the possible combinations four scenarios will be developed. In the next step, driving forces and response indicators were used to describe possible future developments. The latter will be used to formulate storylines, which will be finalized during two planned scenario workshops in 2016.

**Climate variability and change:** The analysis of the past climate variability require multi-decade long surface station data. The access to daily station observations and to historical time series data was improved substantially in 2015. Contact to the Potsdam Institute for Climate Impact Research were established during the Plant 2030 status seminar, providing access to data from 16 weather stations of Tanzania, while a PhD stipend enabled the access to rainfall stations in Kenya, while the provision of basic equipment ensured access to station time series from Uganda, and a database covering all four target countries has been acquired. Long-term rainfall estimates for 30 years have been analyzed and indices were developed quantify rainfall trends and changes in total rainfall, dryness, rainfall intensity and the occurrence of rainfall extremes. The long rains reveal increasingly variable trends, while the amounts and intensity of the short rains tend to increase (Figure 15, Annex). The number of rainy days increased significantly around Lake Victoria while decreasing in coastal regions, including Ifakara. Key drivers appear to be comparatively warm temperatures of the maritime continent and Western Pacific Ocean, the El Niño Southern Oscillation and the Indian Ocean Dipole, which modify the equatorial Walker Cell. Individual rainfall seasons were defined for all stations, and we are now able to analyze the inter-annual variability of the start, end, and lengths of rainfall seasons. Principal component analysis showed that rainfall on inter-seasonal time scales is connected with atmospheric patterns above the Indian Ocean. The Mascarene High impacts the movement and shape of the Intertropical Convergence Zone and a weak high-pressures system is related with strong rainfall amounts in East Africa. An analysis of general circulation models of the Coupled Model Inter-comparison Project Phase 5 and of the regional climate models from the Coordinated Regional Climate Downscaling Experiment reveal similar projections for East Africa. We studied 42 model combinations for the periods 2040-2059 and 2080-2099 regarding the Representative Concentration Pathways 4.5 and 8.5. During the mid-21st century, annual rainfall reveals an increasing trend. However, reliable precipitation projections for the long rainy season are at present not possible. In contrast, more robust and higher rainfall amounts are projected for the short rainy season. The comparison of RCPs indicates that more greenhouse gases increase precipitation changes. The projected trends towards more variable rainfall are likely to increase riskiness of upland production and increase pressure on wetlands.

**WP-C3: Scaling**

**Abstract:** The application of integrative trans-disciplinary modelling and scaling approaches is required to understand and characterize the complexity of wetlands at different levels of system organization. Boundary conditions describing the physical, biological, and socio-economic conditions in the vicinity of wetlands must be quantified. The following scaling process is aimed at understanding and quantifying the interrelation between wetland constituting system components. The workpackage has thus a strong integrating character. A resulting wetland model will be used for generating scenarios based on scientific insight and will be made available for decision support and policy briefing.

**Objectives:** The overall objective of this project is to provide an integrated wetland model and trans-disciplinary scenario simulations for regional up-scaling (Cluster D). Following activities are implemented to reach this goal: (i) establish boundary conditions; (ii) scale from plot to wetland; and (iii) model wetland use scenarios.

**Activities and key findings**

Modelling group meetings held in 2015 developed the wetland model concept for scenario calculations. General characteristics of system structures and boundary conditions were explained and the importance for developing a trans-
disciplinary integrated wetland concept stressed. Initial meetings aimed at defining entities and entity relations, covering all research areas and disciplines. Information from questionnaires administered in 2014 and related literature was compiled into an ontology comprising wetland aspects of agronomy, ecology, economy, ecosystem services, geography, greenhouse gases, human health, hydrogeology, hydrology, meteorology, politics, and socio-anthropology. This ontology is a precondition for developing a transdisciplinary understanding of wetland systems and provided the basis for further practical and theoretical analyses. A guiding concept of balancing wetland production and ecosystem services using resource supply-demand scenarios was applied (and the modularized architecture of the generic wetland model has been established. Analyzing the ontology and developing a transdisciplinary understanding of wetland systems required an epistemological method. We decided to apply inductive reasoning, meaning that wetlands are first studied from disciplinary viewpoints and, using the evolving knowledge, the organizational scale is appropriately increased to higher, integrated levels to develop a more holistic understanding of human-environmental interactions. Confronted with an complexity of wetland entity relations, we focus initially on biophysical modelling of wetland dynamics and gradually enlarge the scope towards inclusion of economic and socio-anthropological processes and patterns.

Biophysical modelling initially focusses on the interaction of hydrology and cropping patterns. Hydrological scaling generated soil moisture patterns at the spatial-temporal resolutions required for modelling cropping patterns. The model will answer the question to what extent and in which combination spatial plant functional type characteristics are influenced by hydrological patterns. We therefore established a corresponding SWAT virtual machine on the Wetland computation server in Bonn. The work is also interfaced with ongoing crop modelling work conducted in WP-A2 and WP-B1 in which the APSIM suite is used for characterizing yield-gaps and establishing cropping calendars. The resulting model parameter sets will be transferred to SIMPLACE crop growth model engines for integration with economic and multi-agent modelling activities. The novelty of this approach is the incorporation of biophysical processes into agent- based and land use models. The social-ecological integration for addressing all aspects studied in the “Wetlands” project required the establishment of a modelling framework. Mathematical consequences of model coupling were analyzed and corresponding software engineering options have been assessed with experts, confirming the suitability of the flexible software design of SIMPLACE. As water and humans have been identified as the major drivers of wetland change, the modelling frameworks SWAT and REPASt have been initially selected.

In addition to these mainly biophysical models, we started to include socio-anthropology concepts such as the actor-network theory, treating objects (i.e. wetland entities) as part of social networks. Relevant literature was studied, indicating that the multi-agent toolbox REPASt (applied in economic research of WP-B3) can be also used to model human-wetland interactions, closing the gap between biophysical, economic and socio-anthropological studies, and completing the transdisciplinary research circle by facilitating the assessment of ethical consequences of changing wetland system behavior. Also, spatially-explicit assessments and modelling of land use and land cover change in wetlands (WP-D3) provides information about historical change characteristics and spatio-temporal dimensions of human-caused dynamics in vegetation and management patterns. Since modelling activities in the hydrology, vegetation, geography and economy groups are also spatially-explicit, processes and system dynamics simulated in the wetland model will be grid-based. The required management software has been installed on the wetland server. Finally, African colleagues voiced concern that research appeared to be decoupled from development of wetland policies. The question arose whether the existing functionality of SIMPLACE can be used to develop a decision support tool for wetland experts in East-African ministerial offices. Therefore, the roles of stakeholders were assessed and a workflow has been developed. The concept was presented and endorsed in a technical appendix session of the advisory board meeting in November 2015. Relevant project management software was installed on the Wetland server and potential users were identified. The development of the tool is based on the agile modelling approach ensuring timely cooperation between developers and users in the ministries. The final model design will be discussed during the general assembly meeting and a prototype model will be available at the end of 2016.

3.5 Cluster D: Extrapolation and recommendation

Land use trends and suggested future wetland use scenarios need to be targeted at specific sites or translated into policy recommendations. This implies the definition of social-ecological extrapolation domains for technical options and for future wetland use options to the national/regional scale. Translating local-scale knowledge into policy advice requires the use of regionalization techniques. The DPSIR concept will be applied to analyze drivers (human needs), pressures (human activities to fulfil needs), states (changes in the condition of the environment), impacts (effects of a change in state on ecosystem services), and responses (reactions to losses of ecosystem services) of current wetland use. To answer the question whether and how wetlands can contribute to food security, a balance between food demand and food provision at different scales is required. Food insecurity is caused by bio-physical, technological, educational, and socio-economic constraints. Cluster D aims to translate and transfer knowledge gained at the wetland/catchment scale to decision-makers at policy level at the regional/national scale. Methods and tools developed and results obtained at the test sites are linked with existing approaches for evaluation of sustainable use of wetlands. The five work packages, are closely interlinked, reaching from plot- based targeting of technical options over various scaling activities to policy advise.
WP D1: Social-ecological niches

Abstract: Wetlands present a large heterogeneity of socio-economic and agro-ecological conditions for agricultural uses, which results in unique, niche-like production environments. These socio-ecological niches describe a multidimensional environment for which compatible technologies can be predicted. We postulate that only the matching of technology-specific input requirements with system-specific attributes and expectations will improve the adoption of technology options for sustainable wetland uses and result in tangible improvements of rural livelihood.

Objectives: Based on field agronomic experiments (WP-B1) and economic surveys (WP B1) multivariate statistical approaches will be applied to match resource requirements and performance attributes of technology options with characteristics of the social-ecological systems. Technology extrapolation domains will thus be defined and target environments for most promising options will be mapped for extrapolation.

Activities and key findings

This activity will start after the analysis of the first two years of data from yield gap and technology testing trials at the super test sites, in mid-2016. Production information (WP-B1) will be matched with household economic information (WP-B2) to derive potential gains of selected technology options for a given social-ecological environments.

WP-D2: Human health impact

Abstract: This work package studies the relationships of public health aspects and wetland ecosystems. Health impact assessments are carried out covering physical, mental and social health aspects in relation to different wetland types. The findings are guiding the implementation of theoretical concepts of health impact assessment in wetland settings and link human health considerations to studies on adaptation and coping with global change. Results will also serve as background information for awareness-raising campaigns.

Objectives: The research will deliver an understanding of health aspects associated with wetland ecosystems by: (i) developing a tool for health assessment; (ii) assessing physical, mental and social health aspects; (iv) providing a wetland malaria risk assessment; and (v) guiding a health-sensitive wetland management.

Activities and key findings

Increased use of wetlands has implications on the health of wetland users, who may on the one hand be exposed to different water-related health risks, on the other hand, may benefit from increased food security and improved food quality (i.e., vegetables). On the basis of the wetland types and environmental conditions, an overview of potential health risks, but also of benefits arising from wetland uses has been compiled. In the course of the project, this general view will be scaled down to the project areas. The aim is to provide a checklist, which is used for a Health Impact Assessment. Based on this output and results from WPs A1 and A5, guidelines for health-sensitive wetland management aspects will be developed in the second project phase. With the completion of the data collection the development of the Health Impact Assessment tool has started in mid-2015.

A survey and observational assessment of physical health was conducted on water-related diseases associated with the use of wetlands. Health risk perception and behavioral studies covered 400 households in Kenya in 2015. Furthermore, 20 individuals were chosen for in-depth interviews on specific wetland-related diseases and six experts from the fields of public health, environmental and water management and education were interviewed. First results show that people use the wetland mainly for crop production, livestock grazing and the extraction of domestic water. Their knowledge on water-related diseases and their transmission pathways is limited, and few apply preventive health measures. Water supply, sanitation and hygiene are inadequate for large parts of the population but significantly differ between different user groups. The respondents associated inadequate water-related hygiene with unsafe water sources, water scarcity, multiple water uses, a lack of sanitation facilities, open defecation and livestock interaction. WASH-related behavior is determined by the physical environment, lifestyle, tradition, habits and education. Simultaneously, a comprehensive literature review on water-related diseases in Sub-Saharan African wetlands and use-related exposure has been conducted. The findings confirm that different wetland uses entail different health risk factors Based on this review, a conceptual framework displaying a detailed overview on disease risk factors related to wetland use has been developed.

Mental and social health aspects are being studied in Uganda. A cross-sectional survey on the status of well-being and mental health has been carried out with 235 randomly-selected individuals. Large differences of the social fabrics in the wetland basin could be detected. A correlation between life satisfaction and place attachment was shown. Especially subsistence farmers are highly dependent on the wetland and also emotionally attached to the landscape. They identify with the wetland as part of their livelihood. The qualitative data resulting from group interviews in 2015, have been partly analyzed. Beside basic needs like money and a family, the property of farm land plays an important role for the well-being. The wetland itself is perceived as main source of water for daily needs, particularly during the dry season. Place attachment is mainly driven by the social fabric, and has a high impact on the place-related well-being of people deriving their livelihood from the wetland. Key issues related to wetlands influencing the mental well-being are land use conflicts,
WP-D3: Quantification of wetlands in space and time

Abstract: Wetlands are diverse and potentially highly productive ecosystems. While awareness of the manifold values of wetlands is increasing, transformation processes - as triggered predominately by population growth and climate change - modify and convert wetlands in unprecedented ways. By combining multi-temporal datasets from different radar and optical satellite systems, actual, recent-past and future wetland areas and uses are being classified. Understanding past and current land use changes and their driving factors will allow projections of future wetland use scenarios.

Objectives: Building on the knowledge of the natural and human-induced characteristics of wetlands, and on the understanding of the fundamentals of remote sensing, it is assumed that microwave sensing offers the opportunity to detect wetland areas. Based on the complex heterogeneity and seasonality of study wetlands in the four target countries, the combination and integration of different sensors operating at different wavelengths and spatial resolutions will enhance the spatial-temporal quantification of wetland areas. The main aims are (i) the delineation of wetland areas; (ii) the classification of land-cover and land-use; and (iv) the development of a land-use / land-cover change models.

Activities and key findings

Wetlands’ wise management requires knowledge about their locations and sizes. While people on the ground might be aware of their valuable resource base, institutional stakeholders need a quantitative spatial knowledge base. These requirements can be met by remote sensing data and techniques as they contribute on different spatial scales and resolutions by providing spatial explicit knowledge. Regional wetland maps do not exist for the project countries in East African. We thus compiled satellite data and prepared their analysis for the whole study region in 2015. Based on a draft processing chain (Figure 18, Annex), input datasets were prepared. The delineation of wetlands areas was based on a morphometric analysis using a Digital Elevation Model A time series analysis of a 15 years MODIS NDVI datasets with a composite period of 16 days each) was conducted and followed by a stratification of the study area based on temporal vegetation profiles. A combination of morphometric and time series analyses yielded a lake mask (permanently inundated areas) which was accuracy assessed based on high resolution satellite image composites and the ‘Global Lakes and Wetlands Database’ (LEHNER & DOLL., 2004) and is ready to use. A Sentinel 1 SAR mosaic of dual polarized scenes which cover the complete project region was preprocessed and is ready to use for an image segmentation which will feed into the time series analysis of MODIS data (Figure 16). Multi-temporal and multi-polarized SAR images were used for soil moisture retrieval. Radar satellite data proposals were submitted. The TerraSAR X proposal was accepted in January 2015 by DLR and the RadarSAT 2 was accepted by MDA in March 2015. The radar images are being used in soil moisture retrieval for Ifakara (Figure 19, Annex). Vegetation and soil roughness data will improve the accuracies in soil moisture retrieval. Field campaigns were conducted on the same dates as the satellite passes to calibrate remote-sensed data with real time measurements of subsurface soil moisture, leaf area index and soil roughness. While data from the field during the first campaign are processed, those of the second campaign are still under analysis. Preliminary findings suggest that vegetation cover has a significant effect on the soil moisture retrieval results.
Consequently, the RapidEye images have been re-classified with the aim of assessing the vegetation cover and estimate the water content of the vegetation. Additionally, vegetation indices are also being analyzed.

Land use and land use change mapping was based on a hierarchical land-cover and land-use classification scheme of Landsat data. Since the dynamic cover types within the Kilombero floodplain can only be adequately captured when multi-seasonal datasets are used, we generated wet season and dry season composites of the RapidEye and Landsat images. Manual improvement of the cloud mask was required. An overlay of dry season and wet season results allows for the identification of rather stable versus dynamic classes respectively. This information can then be used to classify land cover and land use on the second level (Figure 20, Annex). Figure 21 shows a classification result at a larger scale in the area around the fringe, middle and central super test sites, including maximum flooding extent. A preliminary land use map from the Uganda site was generated and will be further improved by using Sentinel-2 data.

**WP-D4: Regionalization of sustainable wetland use**

**Abstract:** Policy advice concerning the sustainable use of wetlands requires regionalization of the findings from the test site studies to the national scale. Due to scale-dependent data constraints, this can only be performed by a change in model concept. Biophysical as well as socio-economic aspects have to be considered, based on the Driver-Pressure-State-Impact-Response (DPSIR) framework. The overall aim of this work-package is to develop a methodology for recommending wetlands to be used for food production in a sustainable way at the regional/national scale.

**Objectives:** Based on knowledge and data at wetland and catchment scales combined with statistical modelling, we will develop a methodology to identify and map wetlands at the national scale, which can be used in future without deteriorating ecosystem services. A multi-criteria analysis based on the DPSIR concept will be developed to quantify current impacts of wetland use depending on drivers and pressures. The outcome will provide (i) the actual wetland status; (ii) the potential wetland food production; and (iii) the future wetland potential under Global Change.

**Activities and key findings**

With the aim to develop a methodology for extrapolating recommendation domains for future wetland uses, data collected at wetland and catchment scales were combined with statistical modelling, thereby developing a methodology that allows identifying and map wetlands at national scale. In preparation for the study, a methodology to identify and differentiate inland valleys and floodplains on a regional scale from topographic and hydrological indices has been developed and applied to the typology data set. Additionally, as hydrological data of the entire project region are a prerequisite for regionalization, an East African hydrological database has been compiled from public domains and is currently updated. Two rainfall-runoff models that are driven by global climate data and discharge data from regional water authorities have been calibrated and validated for the study catchments in Kenya and Tanzania. Further activities in the workpackage build on the outcome of wetland typology (WP-A1), and will start only after completion of the assessment of ecosystem services (WP-A4), water and matter fluxes (WP-A5), technology evaluations (WP-B1), digitalization of wetland use maps (WP-D3), and the development of the integrative wetland model (WP-C3).

**WP-D5: Policy Advice**

**Abstract:** Translating research results into effective problem-solving actions is a challenge for both researchers and policy makers. Agricultural research results communicated conventionally in scientific publications have often failed to make the desired impact. Decision makers must be involved at the early stages of research planning and research must be packaged both for decision-makers at policy level and for practitioners into summarized and simplified messages. Translating research results into effective and compelling messages does not only involve the interpretation of results for “non-experts”, but also incorporate considerations for anticipating and overcoming obstacles to policy reform and implementation. Policy-makers were involved in the formulation of the aims and objectives, and the results generated in the work packages on wetland characterization, sustainable use options and scaling issues will be communicated in workshops and awareness campaigns, and findings are compiled into policy briefs and delivered to decision-makers.

**Objectives:** We establish an understanding of current policy frameworks regarding wetlands within the political and economic settings of the study countries and develop a policy advice framework to effectively implement research results.

**Activities and key findings**

Cross regional policy assessment: A policy economist from Rwanda has been recruited in late 2015. He will conduct a comparative analysis of wetland policies in the four target countries using the Policy Analysis Matrix and assess measures of implementation and enforcement of wetland-related rules and laws and their impact on protection and uses of wetlands in the region.
3.6 Cluster E: Capacity-building

The sustainability of the planned research on wetlands potentially becoming the future food basket of East Africa requires a set of capacity-strengthening measures to deeply root the knowledge generated within the project. Capacity-building measures include well-targeted investments in education and training to strengthen scientific capacities and communication approaches that foster interaction of scientists and practitioners and with the policy communities. Definitions of capacity-building (often refereed as capacity development or capacity strengthening) vary widely. Cluster E aims to (i) strengthen the research and development capacities of the African partners, (ii) expand and strengthen North-South as well as South-South networks (pooling already existing structures), and (iii) implement findings and easy-to-use decision tools at field, community and national levels.

Cluster E: Capacity-building

Abstract: The prerequisite for a sustainable implementation of the research findings on a “wise” use of wetlands is a sound and well-targeted multi-level capacity-building. We aim to build a regional expertise on wetland-related issues, serving as a nucleus for a long-term engagement in food security research, beyond the four target countries and beyond the life span of this project. Besides the academic education of students, we implement knowledge- and skill-enhancing measures (i.e. field schools and workshops), also for other stakeholders. Workshops and conferences address scientists from other African countries as well as international parties from research, policy and development.

Objectives: Capacity-building aims to deeply root the knowledge generated within and beyond the target region by the following measures: (i) strengthening the African academia; (ii) enhancing knowledge and skills of stakeholders; and (iii) implementing knowledge, tools and policy briefs in the wider community.

Activities and key findings

Thirty mainly African master students and 24 PhD students (42% in total and 43% funded by project scholarships with African nationality) have been recruited or have completed their studies until end of 2015. For 10 MS and 3 PhD student, external funding could be secured. Ten master theses have been submitted. A complete list of all PhD and master students with research topics and short abstracts can be found at http://www.wetlands-africa.de/staff, and the finalized master theses are listed under http://www.wetlands-africa.de/publications. Full-text versions are accessible to project members on the “internal” pages. Beside trainings of students, individual and group trainings of research assistants, enumerators and field assistants took place in all target countries. Additionally, five workshops have been organized up to now, with >160 participants Topics ranged from “anthropological research design methods”, “valuation of ecosystem services” and to “environmental monitoring using UAV systems”. Further workshops are in preparation for early 2016. These contributions strengthen regional capacity on wetland-related issues and will continue and be expanded in 2016.

4. DELIVERABLES AND MILESTONES

Most milestones for 2015 have been accomplished. Despite some delays in setting up the infrastructure in some target countries, slight delays in student recruitments and a late start of the central field experiment in Tanzania, we expect to reach the envisioned milestones also for the coming years. Until end of 2015 one book and ten (4 peer-reviewed journal, 3 reviewed extended abstracts and 3 submitted to the review process) articles have been published or submitted. Additionally 21 oral contributions and 25 posters have been presented at national and international conferences. All PhD and most master thesis results are expected to be published as articles in the future. Further information on publications are available at: http://www.wetlands-africa.de/publications.

The “Wetlands” project’s aims of assessing the potential for sustainably transforming wetlands of East Africa, and to develop science-based tools facilitating decisions on protection or wise use are well under way. We are confident to contribute substantially to reconciling growing needs for food production with concerns for wetland protection through trans-disciplinary research approaches.


Mathias Becker

Bernd Diekkrüger
Figures

The following figures present selected highlights of finding in 2015 and are listed in the order they are referred to in the annual progress report.

**Figure 1:** Conceptualization of linkages between a) work clusters and b) disciplinary areas.

**Figure 2:** Schematic presentation of linkages between research clusters and work packages.
Figure 3: Distribution of WET-health scores according to four assessment modules among localities, land use classes and flooding regimes (adapted from Beuel et al., 2016). Scores vary from 0 (un-impacted units) to 10 (complete loss of wetland properties in the assessed unit). Width of bars indicate the relative frequency of the single scores in the respective column, while dots connected by dashed lines show the trend of the median values.
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Appendix

Figure 4: Experimental design of the central field experiment at the super test site in Namulonge, Uganda

Figure 5: Horizontal variability in selected soil attributes at the super test site in Namulonge, Uganda

Figure 6: Vertical distribution of bulk density at the super test site in Namulonge, Uganda
Figure 7: Display of summaries for taxonomic lists in an R console (left) using the package “taxlist”. The current version of the list of vascular plants for East Africa (EA-Splist) contains 3,026 names for 2,579 taxa (mainly species). The display below shows all alternative names stored for *Cyclosorus interruptus*, which is a fern species common in papyrus marshes (picture right).

```r
> library(taxlist)
> Easplist <- taxplist("Easplist")

> summary(Easplist)
3026 names for 2579 taxa
1 (0%) taxa with first name entries
0 variables for taxon traits
validation for class 'taxlist': TRUE

> summary(Easplist, 50074)

# Valid name for taxon concept '50074':
50074 Cyclosorus interruptus (Willd.) H. Itó

# First name:
52443 Pteris interrupta Willd.

# Synonyms:
52002 Dryopteris gongylodes (Schkuhr) Kuntze
52002 Thelypteris interrupta (Willd.) K. Iwats.
52008 Cyclosorus striatus Ching
52443 Pteris interrupta Willd.
52444 Aspidium continuum Desv.
52445 Aspidium ecklonii Kunze
52446 Aspidium gongyioides Schkuhr
52447 Aspidium obtusatum Sw.
52448 Aspidium pteroides (Retz.) Sw.
52449 Aspidium serrata (Sw.) Sw.
52450 Aspidium serratum Sw.
52451 Aspidium unicum (L.) Sw.
52452 Nephroidium propinquum R. Br.
```

Figure 8: Display of summaries for a vegetation database in an R console (left) using the package "vegetables". In the current version imported from Turboveg about 3,000 plots are stored. The map (right) shows the distribution of plots collected in East Africa.

```r
> library(vegetables)
> Sweedstavreg <- importVegTable("Sweedstavreg")
Reference list used: Easplist

> print(Sweedstavreg)
db.name: Sweedstavreg
sp.list: Easplist
dictionary: Swea

3033 observations of 2443 species.
60 variables with records.

[2016-04-01 09:30:06]: data imported from 'Sweedstavreg'
```
Figure 9: Succession in the uncultivated plots (T1) in Namulongo. The left graph shows the development of aboveground biomass per m² and the right graph the abundances of selected species. Values in both graphs are mean values of each 4 replications per block. Error bars in the left plot represent the standard deviation of the mean value.

Lemnetea minoris Koch & Tüxen ex den Hartog & Segal 1964
Salvinio-Eichhornietalia Borhidi ex Borhidi, Muñiz & del Risco 1979
Pistion stratiiotis (Schmitz 1971) Schmitz 1988
Lemno paucicostatae-Pistietum stratiiotis Lebrun 1947 [HY1]

Potametea Klika ex Klika & Novák 1941
Nymphaetalia loti Lebrun 1947
Nymphaeion loti Lebrun 1947
Nymphaetum loti Lebrun 1947 [HY2]

Phragmito-Magnocaricetalia Klika ex Klika & Novák 1941
Papyrus Lebrun 1947
Papyrus Lebrun 1947
Cypero papyri-Dryopteridetum gongylodis (Germain 1951) Schmitz 1963 [HE1]
Magno-Cyperion divitis (Lebrun 1947) Schmitz 1988
Cyperetum latifolii (Germain 1951) Schmitz 1988 [HE2]
Echinolchion crus-pavonis (Léonard 1950) Schmitz 1988
Pycreo polystachyos-Panicetum subalbidum ass.nov. [HE3]

Phragmitetalia communis Koch 1926
Phragmitition communis Koch 1926
Ipomoeo aquaticae-Typhetum domingensis ass.nov. [HE4]
Phragmitetum mauritanii (Lebrun 1947) Schmitz 1988 [HE5]
Leersio hexandrae-Cyperetum exaltati ass.nov. [HE6]

Oryzetea sativae Miyawaki 1960
Amarantho-Ecliptetaia Schmitz 1971
Ecliption albae Lebrun 1947
Centrostachyo aquaticae-Persicarietum senegalensis ass.nov. [HE7]

Hyparrhenietaea Schmitz ex Hoff & Brisse 1983
Themedetalia triandrae Lebrun 1947
Themedion triandrae Lebrun 1947
Cypero rotundi-Sporoboletum fimbriati ass.nov. [TE1]

Figure 10: Syntaxonomic scheme for aquatic and semi-aquatic vegetation in East Africa. Hierarchical structure is indicated by the suffix of syntaxon names, namely for class (-etea), order (-etalia), alliance (-ion) and association (-etum). Grey shading indicates codes used by Alvarez (2015) and the abbreviation ass.nov. is provided for associations described in the cited work.
Figure 11: Reference collection of selected invertebrates collected from disturbed wetlands at Ewaso Narok in Kenya
Figure 12: Hydrogeological conceptual model of the super test site Ifakara.

Figure 13: Main uses of wetland resource in the Kilombero floodplain of Tanzania
Figure 14: Main reason for growing crops in the Kilombero floodplain of Tanzania

Figure 15: Linear trends of seasonal rainfall amounts of satellite based rainfall estimations with regard to the period 1983-2014. Significant trends in terms of the 5% level are bordered. (a)-(c) March to May (MAM), (d)-(f) October to December (OND); (a)+(d) Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS), (b)+(e) station observations, (c)+(f) Precipitation Estimation from Remote Sensed Information with Artificial Neural Networks (PERSIANN).
Figure 16: Illustration of final stages of future wetland developments. The prototypes are called: “Rice”, “Papyrus”, “Tomatoes” and “Bricks” (see text for more information).

Figure 17: Coordinate system regarding the scenario development. The “economic development” is aligned at the abscissa and the "level of organization" is positioned at the ordinate.
Figure 18: Simplified draft processing chain for data processing by remote sensing

Figure 19: A Sentinel 1 SAR mosaic of dual polarized scenes which cover the complete project region was preprocessed and is ready to use for an image segmentation which will feed into the time series analysis of MODIS data.
Figure 20: RapidEye image composites for a) dry season, and b) rainy season. Each composite is generated from up to six single images which are clouded to a certain extent (approx. 5-50%), white areas indicate gaps that could not be filled with any of the images. Level 1 classification results of c) dry season, and d) rainy season. Four very broad classes are derived that can be related to dynamic on the ground.

Figure 21: Classified RapidEye images for the wet and dry season. The extent of flooding in the wet season is shown.