TEEB for Agriculture and Food: Kenya Workshop Scoping Report

This summary document has been developed by UNEP-WCMC, in large parts by extending analysis carried out under previous projects (e.g. work looking at future scenarios for biodiversity and commodity production around the Lake Victoria Basin) and / or by deploying models which have been used elsewhere such as in the CBD's Global Biodiversity Outlook report.

Its aim to stimulate thinking on where priorities might be to carry out further analysis and policy development, through using readily available information and tools to help identify and visualise potential implications of changes in agriculture production for biodiversity and ecosystem functions in Kenya under different socio-economic futures and in the face of climate change up to 2050.

The modelling work was supplemented with rapid reviews of internationally available policy documents and literature on natural capital valuation and externalities across agri-food supply chains. Whilst not exhaustive, like the modelling, the reviews are intended to prompt thought around the potential policy hooks and the use of economic valuation.

We hope that it provides a useful starting point for your discussions.

Economic Valuation / Natural Capital Accounting in Kenya

As an introduction to the TEEB related experience in Kenya, this section focusses on commitments to understanding and responding to the values of nature at a general level, rather than focussing in on agriculture, and looks at experience in practice which could be built upon through further work with the TEEB initiative.

International commitments and their translation into domestic policies

Kenya has committed to integrating the values of biodiversity and natural capital into decisions in various different fora.

For example, as a Party to the Convention on Biological Diversity, Kenya has committed to the Aichi Biodiversity Targets, including Aichi Target 2, which requires that "*By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems*".

Similarly, at a regional level, Kenya has been a member of the Africa-led "Gaborone Declaration for Sustainability in Africa" since it was founded in 2012. The overall objective is "*To ensure that the contributions of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being are quantified and integrated into development and business practice.*" It responds to the concern that brought the Heads of State of the original signatory countries together initially which was the historical pattern of natural resource exploitation that has failed to promote sustainable growth, secure environmental integrity and improve social capital in Africa.

Efforts to achieve these international objectives have also been translated in domestic policy. For example:

- In Kenya, the long-term development plan - Kenya Vision 2030, aims to transform the country into "a newly industrializing, middle-income country, providing a high quality of life to all its citizens in a clean and secure environment" by 2030.
- The role of natural capital assessment, valuation and natural capital accounting in securing long-term economic growth and societal well-being is explicitly recognised in Kenya's 5th Report to the Convention on Biological Diversity (GoK, 2015).
- Kenya's State of the Environment report explicitly recognises the role of environmental accounting as a means of enabling Kenya's businesses to internalise environmental externalities (Reuter et al., 2016).

Valuation in practice

There are some good examples of applications of the TEEB Approach in Kenya, with a range of examples of efforts to ensure that the value of nature is demonstrated and recognised in decisions. There are also some examples of the development of schemes to capture the values and deliver financial benefits for environmental improvements. The brief review of experience highlighted that:

- Valuation efforts are visible at both the national and sub-national level in Kenya.

    - The Poverty-Environment Initiative was used to deliver capacity building support in economic valuation of environmental and natural resources among government ministries and institutions.
    - UN Environment, in collaboration with the Government of Kenya, completed a cost benefits analysis of the value of lost regulating ecosystem services against the revenues from timber logging and fuel wood yields associated with montane deforestation. The report identifies the value of lost ecosystem services substantially exceeds the revenues realised via deforestation. Noting in the context of this workshop that over 70% of the cost the environmental externalities associated with deforestation were borne by the agricultural sector.
- Payments for ecosystem services (PES) schemes have been used in Lake Naivasha and the Kitengala Land Lease Programme. They have been used to pay farmers to change management practices, plant trees and to pay compensation to farmers to allow wildlife access to their lands rather than use them for grazing. There are also four REDD+ projects identified in Kenya, which provide payment for carbon sequestration / storage ecosystem services.
- A further summary of valuation evidence of potential relevance is provided on the next page.

Developments in Natural Capital Accounting

With specific reference to natural capital accounting, a desktop review of experience across the member countries of the Gaborone Declaration for Sustainability in 2016 highlighted that whilst there was some experience of natural capital accounting in Kenya, whilst this is restricted to the forest sector there are ongoing with respect to both carbon and ecosystem accounting. The work reported was as follows:

- Forest Resource Accounts were produced in 2009 by the Kenya Forest Service and the Kenya National Bureau of Statistics. The accounts focused on timber and non-timber forest products. The accounts revealed that forests actually contributed 3.6% to GDP, rather than the 1.1% listed in the national accounts. This insight resulted in an increased budgetary allocations to forest management activities.
- National Carbon Accounting system: This is a programme of work being implemented as part of Kenya's REDD+ work.
- Forest ecosystem accounting: This is identified as part of the ongoing Miti Mingi Maisha Bora (MMMB) programme of work under bilateral program between Finland and Kenya that provides support to forest sector reform.

Transboundary decisions

Kenya shares borders with Uganda, Ethiopia, Somalia and Tanzania. These are important in a number of contexts with respect to biodiversity, ecosystem services and their role in economic development. For example, there are a number of migratory routes for big games species between northern Tanzania and Southern Kenya highlighted in Kenya's 5th Report to the Convention on Biological Diversity (GoK, 2015). The World Tourist Organisation suggest that watching this type of wildlife accounts for 80% of the total annual trip sales to Africa for the participating tour operators (WTO, 2014) highlighting the importance of transboundary assets in the context of the wider green economy.

Summary of ecosystem service valuation and assessment studies for Kenya with potential links to agriculture (drawn from reviews provided by Reuter et al. (2016) across the GDSA countries and Wangai et al. (2016) with respect to more general ecosystem service assessments in Africa)

Study Name	**Agency / Institution**	**Summary**	**Reference**
Estimation of the costs of soil erosion	World Agroforestry Center/International Center for Research in Agroforestry	Estimated that annual soil erosion losses at a national scale were equivalent to USD$390 million per year (Reuter et al., 2016)	In Reuter et al. (2016): Cohen, M.J., Brown, M.T., and Shepherd, K.D. (2006) Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. Agriculture, Ecosystems, and Environment 114:249-269
The Kenya Atlas	World Resources Institute	The report details: ecosystems and ecosystem services; spatial patterns of poverty and human well-being; spatial statistics related to water, food (agriculture, livestock, fishing, hunting gathering, biodiversity, tourism, wood). (Reuter et al., 2016)	In Reuter et al. (2016): WRI (ND) Executive summary: nature's benefits in Kenya, an atlas of ecosystems and human wellbeing. WRI: Washington, DC, USA.
Trade-offs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa	ICRAF	A national study of 2 provisioning and regulating ecosystem services from mixed-ecosystems based on valuation approaches	In Wangai et al., (2016): Swallow, B.M., Sang, J.K., Nyabenge, M., Bundotich, D.K., Duraiappah, A.K., Yatich, T.B., 2009. Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa. Environ. Sci. Policy 12 (4), 504–519.
Valuing ecosystem services for conservation and development purposes: a case study from Kenya	International Livestock Research Institute	A regional study of 4 provisioning, supporting and cultural ecosystem services from wetland ecosystems based on valuation approaches	In Wangai et al., (2016): Silvestri, S., Zaibet, L., Said, M.Y., Kifugo, S.C., 2013. Valuing ecosystem services for conservation and development purposes: a case study from Kenya. Environ. Sci. Policy 31, 23–33.
Ecosystem services in Southern Africa: A regional assessment.	Coordinated by the Council for Scientific and Industrial Research with contributions from other organisations	One of 33 SubGlobal assessments undertaken as part of the Millennium Ecosystem assessment. Provides a regional assessment of subequatorial Africa (supported by two basin scale assessments)	SAfMA. 2004. Ecosystem services in Southern Africa: A regional assessment. CSIR. Pretoria, South Africa. Pp.84. Available at: http://www.millenniumassessment.org/documents_sga/SAfMA_Regional_Report_-_final.pdf

Externalities and the TEEB AgriFood Framework

The framework developed by TEEB with respect to agriculture and food encourages decision-makers to consider not just the relationship between agriculture and the surrounding natural habitats upon which it might depend and have impacts, but to think more broadly about externalities all the way from how agricultural products are made, through how they are processed and eventually consumed. This is to encourage thinking about food systems and their relationships with people and nature as a whole given the many interconnections between the various different outcomes that we want from system as a whole, especially in the context of meeting the sustainable development goals.

In this context a literature review of externalities from the production, processing and consumption of food was carried out. It looked at literature from Tanzania and Kenya. The results below were either common to both countries, or where they relate to Kenya alone they are reported as such.

The intention of this review is to highlight the potential range of issues that could be examined and addressed by thinking about the agri-food systems as a whole. It is aimed to stimulate thinking rather than directly propose areas for further work.

Whilst the review below focuses on negative externalities, the TEEB framework encourages the exploration of positive externalities, in particular rural employment in the context of agriculture. In this context is it noted that the agriculture sector (comprised of industrial crops, food crops, horticulture, and livestock and fisheries) is the backbone of Kenya's economy, contributing with around 26% of GDP, and accounting for 65% of Kenya's total exports. While it also contributes to the formal employment in the country, more than 70% of the informal employment is in rural areas.

Food and Human Health

- In common with many countries there is a dual health burden of under AND over nutrition.
- Obesity and overweightness is more common in women and children living in urban areas.
- Malnutrition remains common, especially in children, with stunting occurring even when parents are overweight or obese. Micronutrient deficiencies are widespread, attributed to lack of dietary variation, especially with respect to the range of fruits and vegetables.
- Non-exclusive breastfeeding is reported to be undermining the health of young children.

Pollutions and greenhouse gas emissions related to food production and consumption

- Agriculture is the main source of GHG emissions in Kenya. This is dominated by animal production, due to methane emissions from enteric fermentation (part of animals digestive processes) and land use change.
- Issues are reported with regard knowledge and practice in the handling, storage, use and disposal of pesticides. Illegal or improper use of carbofuran were reported in particular. This can result in environmental degradation and risks to human and wild animal health.
- Nitrogen deficiency is reported as an issue in the context of soils for food production and security, but production of (and therefore use of) man-made nitrogen fertilisers leads to increases GHG emissions.

- Food waste occurs due to poor post-harvest handling, high cosmetic standards for export and last minute alterations and cancellations of orders.

Erosion, loss of nutrients, land degradation from agriculture

- The literature review revealed this seemed to be an understudied area in Kenya, especially in the last 10 years. More research maybe needed to assess current state.
- Knowledge and perception of farmers, affordability and adaptability are key for soil conservation measures to succeed.
- Pollination services are being impacted by insecticide use. Adjustments to the timings of treatment using insecticides can be used to reduce impact on bees.
- Modelling of future land use can be used to predict areas likely to experience further degradation.

Cultural values related to agriculture

- Cultural changes can be both positive (gender equality) and negative (erosion of indigenous and local knowledge and nutrition transition). Whilst women dominate the agricultural workforce, they often lack decision making power and ownership. Indigenous and traditional knowledge in agriculture is being eroded by changing diets towards those high in animal protein, saturated fat, sugar and refined foods.
- Knowledge sharing in agriculture is mostly face-to-face, in spite of increasing access to technology such as the internet.
- Cultural and social values should be integrated into programmes tackling food security and nutrition.

Status of food security: deficits or surplus in major staple/ energy crops

- There are multiple pressures to food security throughout Kenya, including financial, water supply, post-harvest handling, pest/disease outbreaks, weather and urbanisation.
- Intensification as well as diversification are needed to improve food security. Major staple crops are important, but traditional crops need to be developed. These can improve nutrition which must be considered alongside the volume of food in the context of food security.

Policy backdrop and potential entry points

This short review gives a snap shot of how interactions between agriculture, economic development and the natural environment are referenced in the context of the different objectives in key policy documents and strategies. As with previous sections, the review was not comprehensive, but is aimed to provide an entry point for discussions as to where further work with the TEEB study might be able to help advance integration.

Overall narrative / direction of travel indicated in key strategies and plans

The common context for Kenya's policies and strategies is important. Kenya has a fast-growing population, and a large part of the country is arid. The amount of arable land is comparatively small, and as a result the forest cover and natural ecosystems in these areas have been steadily decreasing over time.

The existence of ongoing competing land uses for expanding human settlements, crop and livestock production and wildlife, among others, create not only an increasing pressure on the natural environment but also exacerbates conflicts.

Insecure tenure rights remain a threat to sustainable agricultural investments, and for operationalizing many of the policy instruments put in place for sustainable natural resource management by communities.

Several policies recognise that even though extension services (to help drive change in agricultural areas) are currently weak, they have a key role to play for the successful integration of environmental considerations in the implementation of agricultural policies.

The wildlife tourism industry is a major source of income that is threatened by agricultural development. If the tourism industry diminishes, livelihoods may be shifted to other activities that could lead to greenhouse gas emissions or derail mitigation efforts.

These interactions are captured various recent policy development that have follow the development of the **Kenya Vision 2030**. Adopted in 2007 this constitutes Kenya's development roadmap until 2030 and, as such, it is strongly linked to other policy instruments.

Overall, it sets out plans for Kenya to be a middle-income rapidly industrialising country by 2030. The aim of Kenya Vision 2030 is to be a "globally competitive and prosperous country with a high quality of life by 2030" therefore aiming to transform Kenya into "a newly- industrialising, middle income country providing a high quality of life to all its citizens in a clean and secure environment". Many of the flagship programmes and projects for 2013-17 relate to agriculture, forestry, livestock, climate impacts and other related issues. The section on agriculture, livestock and fisheries is included under the economic pillar.

The **Agricultural Sector Development Strategy 2010-2020** is the overall national policy for the agriculture sector in Kenya; its goal is to deliver a 10% annual economic growth rate envisaged under the economic pillar of Vision 2030.

Another important aspect of **Vision 2030** is land reform. As a result, the **National Land Policy** was launched in 2009 with the overall objective of securing rights over land and providing for sustainable growth, investment and the reduction of poverty.

The **Food and Nutrition Security Policy** (2011) was developed with the aim of creating synergy to other governmental initiatives, with a view to complementing the Agricultural Sector Development Strategy that addresses key issues related domestic crop and animal production. It aims to deliver "a situation where all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life"

Importantly, climate change is not only within the priorities tackled within the environmental policy framework, but also it is covered by specific policies within the agriculture sector. In this respect, the recently launched **Kenya Climate Smart Agriculture Strategy-2017-2026**, aims for the sector to "adapt to climate change, build resilience of agricultural systems while minimizing emissions for enhanced food and nutritional security and improved livelihoods".

Kenya's new **Constitution** outlines a renewed legal and policy mandate which covers a range of issues. Of great significance in terms of the country's environmental governance, it is the overarching legal instrument that governs natural resources in Kenya. It obliges the State to ensure sustainable exploitation, utilization, management and conservation of the environment and natural resources, and ensure the equitable sharing of the benefits accruing. One specific commitment in chapter 5 of the Constitution is to increase tree cover from about 6% to at least 10% of Kenya's land area).

With respect to Kenya's environmental policy framework, the **National Environment Policy** (2013), developed by the Ministry of Environment and Natural Resources, contains detail on the actions to be taken for environmental conservation and sustainable use of natural resources. With the goal of "better quality of life for present and future generations through sustainable management and use of the environment and natural resources", the policy has a strong focus on the integration of the environment into relevant sectoral and cross-sectoral policies through integrated approach to management of the environment and natural resources.

In the specific context of biodiversity the **National Wildlife Conservation and Management Policy** (2017) extensively addresses the relationship between wildlife, agriculture and livestock production and climate change. Based on its overarching goals, the policy aims to achieve the "sustainable management of Kenya's wildlife resources through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes in order to provide for the social, economic, ecological, cultural and spiritual needs of present and future generations; contribute to the sustainable development of the country; and enhance the quality of human life".

Policy mapping

The table below summarises in more detail the readily observable policies, plans and strategies that are likely to be relevant in the context of further work. It is not exhaustive but highlights both the importance and potential challenge in bringing together objectives across all these areas, especially in the context of the Sustainable Development Goals.

Theme	Policy/ Strategy/ Plan	Year of adoption/ revision timeline
Development	Vision 2030 (2008-2030) Third medium term plan (2018-2022) in draft	2007

Agriculture	Agriculture Sector Development Strategy 2010-2020	In final stages of revision.
	National Food and Nutrition Security Policy	2011
	Oceans and Fisheries policy	2008
	National Livestock Policy	2008 (revised in 2015)
	National Agricultural Soil Management Policy	2016
	Ministry of Agriculture, Livestock and Fisheries Strategic Plan 2013-2017	Revised in 2015 Expires in 2017
	Environment Policy	2013
	National and District Environment Action Plans	2008 – 2012, now in revision
	National Biodiversity Strategy and Action Plan	In revision
	The National Wildlife Conservation and Management Policy[	2017
Climate change	National Action Plan for Combatting Desertification	2015-2025
	Climate Change Framework Policy	In draft
	Climate Change Action Plan 2013-2017	2013
	National Climate Change Response Strategy (NCCRS, 2010)	
	Kenya Climate Smart Agriculture Strategy 2017 - 2026	2017 - 2026
	National Adaptation Plan 2015-2030 (NAP 2016)	
	NDC (28/12/2016)	
Land Use	National Land Policy	2009
	Land Use Policy	In draft 2016
	Water Policy	In draft
	Wetlands Policy	2014
	Arid Lands Policy	In draft
	The National Spatial Plan (2015-2045)	

Modelling of agricultural and biodiversity futures

This section summarises a range of modelling work carried out to examine potential future synergies and trade-offs between agriculture, biodiversity and ecosystem services. Much of this builds on work that was previously carried out by UNEP-WCMC looking at the Lake Victoria Basin.

The scenarios used for most analyses described below were adapted from the socio-economic scenarios for the East Africa region developed by the CGIAR programme on Climate Change, Agriculture and Food Security (CCAFS). These four scenarios were framed by two main drivers of change: governance (reactive or proactive) and level of regional integration (fragmentation or strong integration). The scenarios were quantified in terms of national demand for food and other agricultural commodities, yields and production using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model developed by the International Food and Policy Research Institute (IFPRI) The outputs from the IMPACT model where then used by the LandSHIFT land use change model developed by the Center For Environmental Systems Research at Kassel University (Schaldach et al. 2011) to spatially allocate agricultural production within the study area. Simulations were done at high resolution (~1km). The model results were then used to assess impacts on different measures of biodiversity and ecosystem function.

None of the scenarios did not explicitly include a "business as usual" scenario, although all have elements that are consistent with the current situation in various countries. Scenarios in this case are not used to explore alternative future pathways in order to compare them and select a preferred trajectory, but – under the assumption that the future is inherently unpredictable - to support the consideration of future uncertainty in (agricultural) policy development that affects biodiversity and ecosystem services. Succinct summaries of the four scenarios are below. (The scenarios were named by participants at the original CCAFS workshop)

Industrious Ants- strong regional integration and proactive governance. This scenario is characterised by proactive governance, and high regional integration with a wide range of benefits for food security, environments and livelihoods. However, there are difficult international relations, a costly battle with corruption and challenges posed by being competitive with crops and products aimed at domestic markets.

Herd of Zebra - strong regional integration but reactive governance. In this scenario, there is an economic boom where regions reach out to international markets. However, the scenario is not economically sustainable, with trade-offs between food security and the environment, dependency on service and industrial markets, and new vehicles for corruption weakening effectiveness.

Lone Leopards - continued fragmentation but proactive governance. This scenario is characterised by visionary actions carried out by individual organisations and initiatives facilitated by governments. It is a world of winners and losers, with uncoordinated trade and shared resources, instability, selfish behaviors and corruption preventing coordination.

Sleeping Lions - regional fragmentation and reactive governance. This scenario is characterised by massive public mobilisations, international investments, informal trade, a personal sense of community and psychological resilience. Governments in 2030 act in self-interest, allowing rein of foreign interests and making money through crises. It is a scenario with no win-win situations, latent capacity and wasted opportunity. Revolutions are common and lead nowhere.

For one question that considers whether potential for closing yield gaps may have the potential to increase productivity and therefore reduce demand for land conversion, different, simpler, scenarios were used.

We have highlighted the simple questions that each piece of modelling work tried to address and the results that were found. Most of the maps resulting from the different pieces of analysis show results for both Kenya and Tanzania. Only the results for Kenya are discussed here.

It is important to note that these are scenario-based modelling exercises, they are not forecasts, but plausible futures (see Box 1). They are aimed to highlight relationships that might be usefully explored in more detail through work with the TEEB initiative.

Box 1: Scenarios
Scenarios provide future contexts of land use and land use change. These contexts are shaped by socio-economic, political, institutional and biophysical factors such as for example projected population growth, technological developments, environmental policies or climate change. Scenarios are increasingly used by scientists and policymakers to better understand and plan for potential future changes in drivers such as climate change, human population and demands for food and fuel, and to address the associated uncertainties. Scenarios are also used as a tool to bring together stakeholders with different objectives (e.g. from different sectors) to discuss common plausible futures and their pathways.

Does land use change vary under different plausible futures?

The production of staple crops, cash crops and meat increases under all scenarios in order to meet the demands of the growing population to 2015. Variations in results (not presented) among scenarios reflect the different governance and agricultural (investment) policy contexts the scenarios create. For example, under the Industrious Ants the highest production for maize and beef is achieved in 2050 reflecting the strong focus on promoting local and regional food production rather than high-value crop exports in this scenario of proactive governance and regional integration. In the Herd of Zebra scenario (reactive governance), there is instead a strong push for high value export crops. In terms of overall patterns of land use change though, the different scenarios lead similar results (Figure 1).

Projected production increases are due to both expected yield increases and area expansion (Table 1). Different drivers at various levels support increasing production by intensifying on existing land or through area expansion and the balance of the two varies under different scenarios. In Kenya the area of maize is expected to reduce under the Industrious Ants scenario, even though production will more than double due to expected yield increases (Table 1).

The most extensive changes in land use under all scenarios occur in areas of grassland and shrubland, which are converted to crop and pastureland in particular. This is due to the weight of the overarching drivers of projected increases in population and associated demand for food and fibre, increased wealth leading to increased demand for animal products and climate change.

The results show that the influence of population change, urbanisation, increased demand for animal products and climate change on land use supersedes that of the different approaches to governance and regional integration characterising the scenarios. The latter factors may however influence the feasibility of potential measures to avoid some of the projected expansion, or to mitigate some of its impacts.

As patterns of land use change under the different scenarios are similar (Figure 1), only the results for the industrious Ants scenario are presented in the results from here onwards.

Table 1 Relative yield, area and production changes (%) and absolute area change for seven crops for Kenya under the Industrious Ants scenario, between 2005-2050

	Relative change (%)			Absolute area change (x1000 ha)
	Yield	Area	Production	
Maize	126	-3	150	-50.7
Cassava	108	49	209	26.8
Fresh Vegetables	181	59	375	86.0
Rice Paddy	55	306	532	53.7
Coffee	152	11	205	19.4
Dry beans	58	82	187	766.2
Sugarcane	22	70	124	39.1

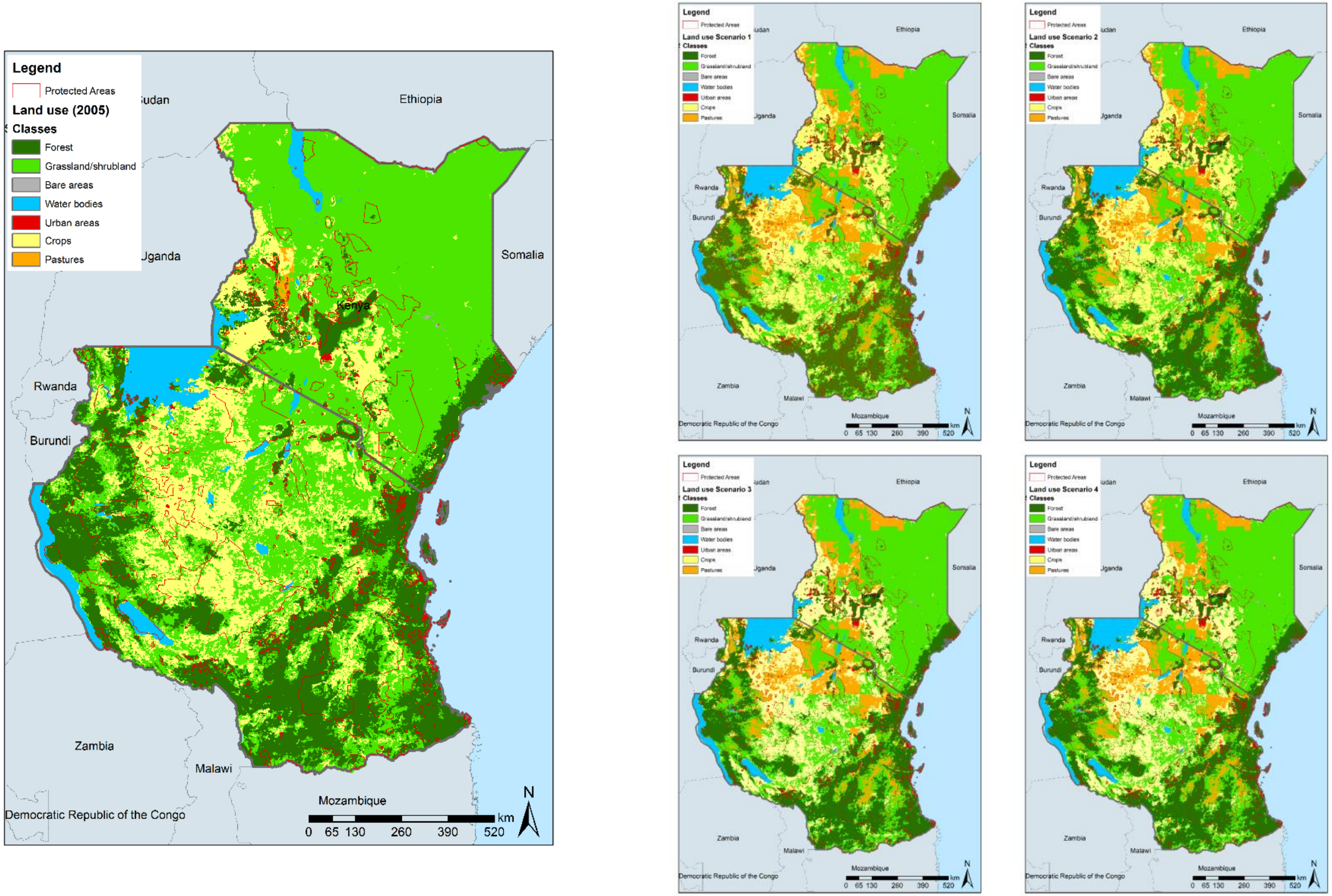


Figure 1 Modelled baseline (2005) and land use under the four East African scenarios in Kenya and Tanzania: Scenario 1, Industrious ants: High regional integration with proactive governance; Scenario 2, Herd of zebra: High integration with reactive governance; Scenario 3, Lone leopards: fragmented and proactive governance; Scenario 4, Sleeping lions: fragmented and reactive governance.

Pressure on biodiversity: where is the pressure on biodiversity in relation to agricultural development?

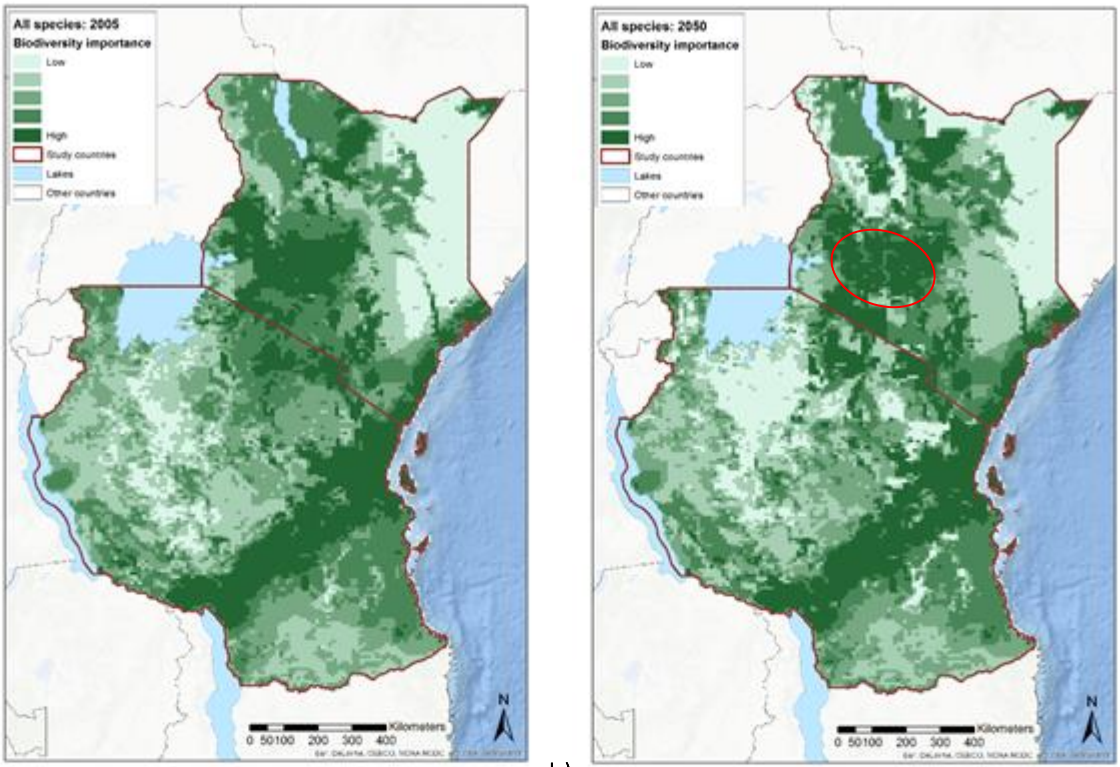
This question was explored using two different approaches to quantify biodiversity and impacts on biodiversity. The first measure of biodiversity uses a global database of threatened species ranges and habitat preferences: the IUCN Red List, the second uses a global database of spatial comparisons of site-level biodiversity under different human pressures: the PREDICTS database (Hudson et al. 2017).

The biodiversity importance index used in Figure 2 is calculated based on the summed relative importance values of the habitat present in each grid cell for each study species. Species range and habitat preference data was sourced from the IUCN Red List of threatened species.

The community abundance (total number of individuals within the sampled community) maps in Figure 3 show a modelled biodiversity metric that can be used to assess the direct impacts of land use change on biodiversity produced using the PREDICTS database (Newbold et al. 2015). The 2005 baseline map shows community assemblage relative to that of a landscape assumed to be composed of entirely unused primary vegetation (Newbold et al. 2015).

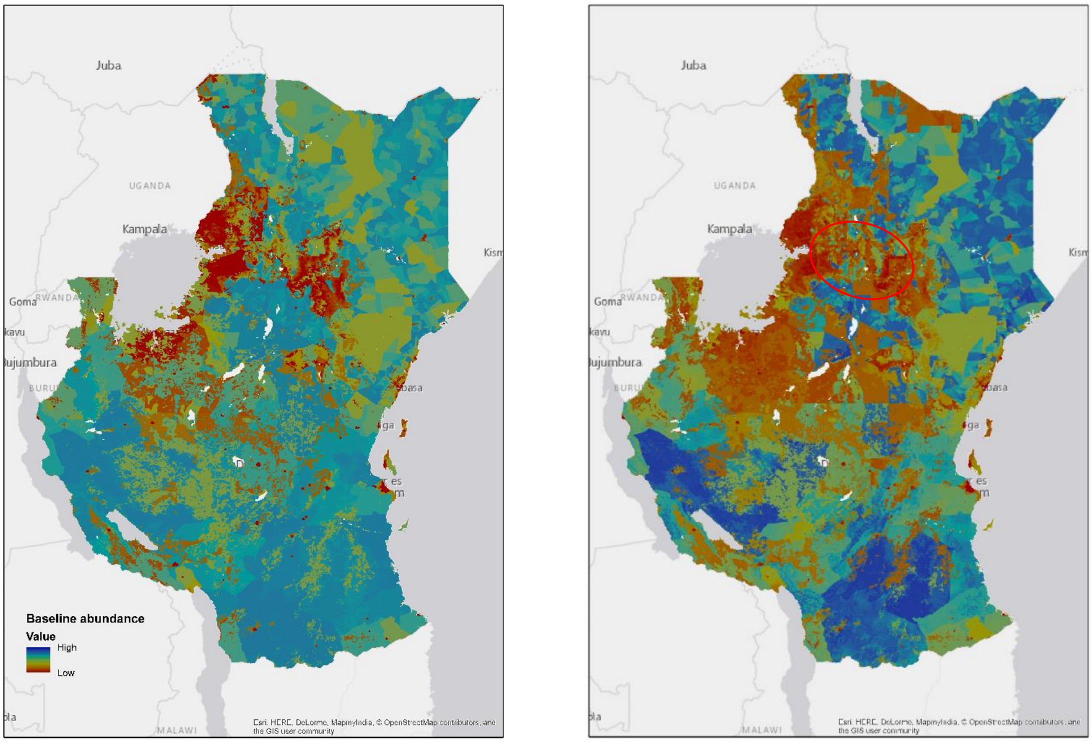
In Kenya, the areas of highest biodiversity loss due to future agricultural land use are in the forested area of southwestern Kenya: the Mau forest and the Aberdares (Figure 2), which are biodiversity hotspots. Conversion from forest (broadleaved evergreen) to cropland (Figure 1) appears to be driven by wheat and temperate cereal crops in this area, although there is less confidence in the LandSHIFT model results for cropland when shown as disaggregated into separate crop types. An analysis conducted using different scenarios (see further in the text) to assess the potential implications of closing yield gaps on the need to expand cereal production reveals a similar picture (Figure 9 and Figure 10). Conversion of grass/shrublands to pastures to meet an increased demand for meat under all scenarios (Figure 1) leads to biodiversity loss amongst others in the north and northeast of the country and north of the Maasai Mara (Figure 2 and Figure 3).

It is noteworthy that according to the analyses of community abundance (Figure 3, a), some of the areas in Kenya with high baseline biodiversity importance according to the metric based on the IUCN Red List (Figure 2, a) had already lost significant biodiversity prior to 2005. This includes areas around Lake Victoria and Mount Kenya.



a) b)

Figure 2 Maps showing biodiversity importance for: a) 2005 (baseline) and b) 2050 under the Industrious Ants scenario. Data for amphibians, birds and mammals were used as a proxy for biodiversity and linked to land use data from the LandSHIFT modelling framework



a) b)

Figure 3 Maps showing community abundance levels for a) at 2005 baseline. b) Change by 2050 predicted under the Industrious Ants scenario. The 2005 baseline map shows community assemblage relative to that of a landscape assumed to be composed of entirely unused primary vegetation (Newbold et al. 2015)

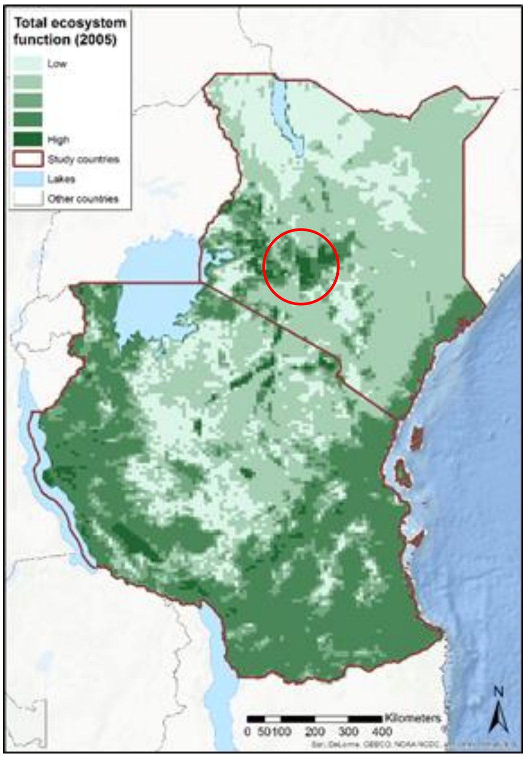
Ecosystem function trade-offs: where are trade-offs among agricultural commodity provisioning and regulating and wild provisioning likely to take place?

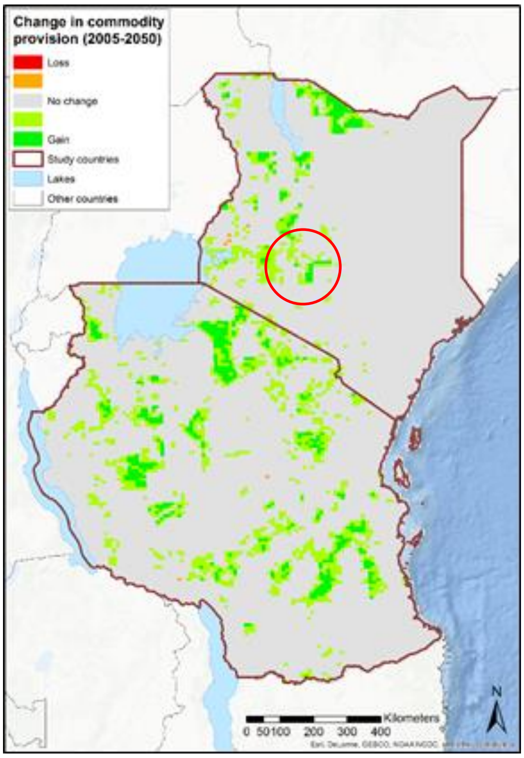
Overall ecosystem function provision

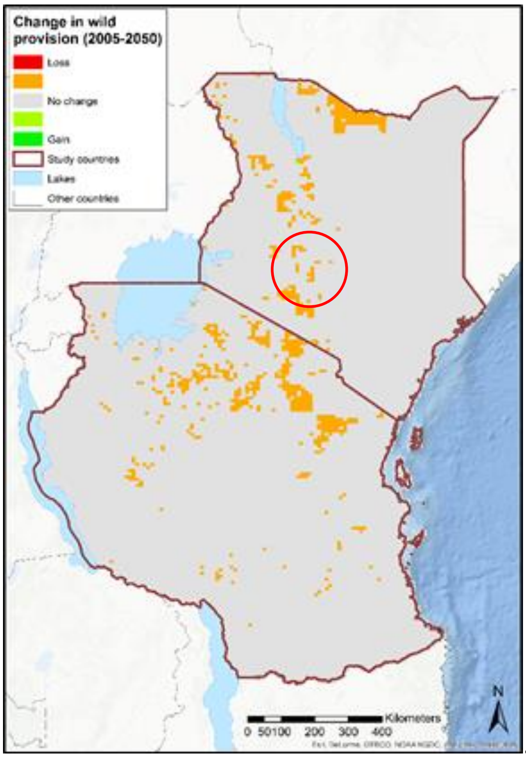
The ecosystem function provision metric describes the capacity of a given land-use type to provide ecosystem goods that can be (but are not necessarily) used by beneficiaries (services). The metric is derived from expert and literature-driven binary links between specific land uses and other environmental properties and the ecosystem functions these properties can provide (Kienast et al. 2009). Agricultural yields and livestock densities are not considered in the provision metric and so differences in production from similar areas would not yield different provisioning values in the maps of Figure 4.

Increases in commodity provision trade-off with wild provision and regulating services where grass and shrublands are converted to pasture, e.g. to the east of Lake Turkana, and broadleaved forest to cropland: from Mount Elgon in the west to Mount Kenya in the Centre, via Kakamega forest, the Mau and Aberdares (Figure 1, Figure 4). Loss in regulating services is strongly associated with forest loss (Figure 4,d), whereas loss of wild provisioning is more scattered (Figure 4,c). The Aberdares are highlighted in Figure 4 to illustrate where conversion from forest to cropland results in trade-offs among commodity provision and the wild provision and regulating services provided by forest landscapes.

Hotspots of ecosystem function in Western and Central Kenya from Mount Elgon to South-Western Mau to Mount Kenya (Figure 4,a) correspond to areas of high biodiversity importance (Figure 2, a). However, the hotspots for biodiversity importance to the East of Lake Turkana and around Mandera do not score highly in the ecosystem function metric. This reflects the difference in dominant land use types between these areas, areas of that score highly for ecosystem functioning are often dominated by a mixture of forest and cropland, whereas areas dominated by grass nd shrubs contribute comparatively less to the ecosystem functioning score.

a) 

b) 

c) 

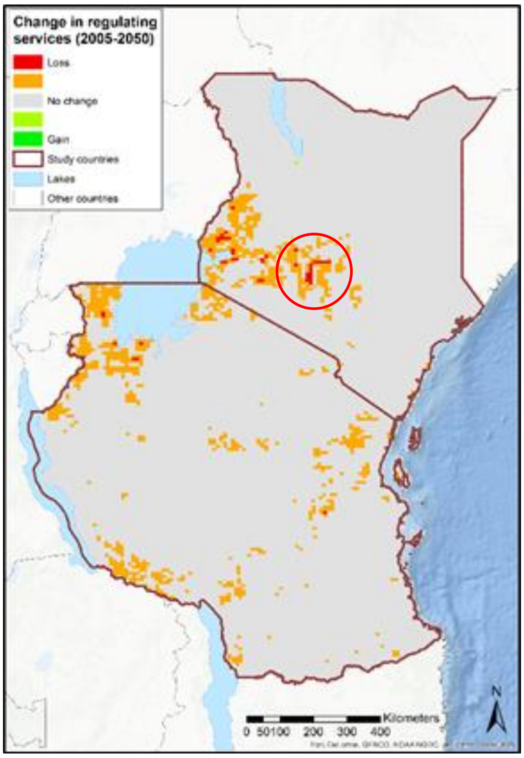
.d) 

Figure 4 Maps showing: a) total ecosystem function provision for 2005 (baseline) and ecosystem function change to 2050 broken down by b) commodity provisioning (crop, pasture), c) wild provision (wildlife, water) and d) regulating services provision. Ecosystem function categories were linked to land use data from the LandSHIFT modelling framework. Results are shown for the Industrious Ants scenario and we assume no land use change within protected areas

Understanding the trade-offs between different ecosystem function types at this level can be useful to ensure the gains in commodity provision required to meet the growing demands for food by 2050 are concentrated in areas that are not projected to have associated losses of other ecosystem functions (wild provisioning and regulating services).

Hydrological services

The impacts of land use change on water-related services were modelled using the WaterWold model. The WaterWorld model was parameterised with input data from the LandSHIFT land use model for baseline and future conditions for land use data.

Due to the projected decreases in tree cover, the total net water use by vegetation for the whole of Kenya reduces by an average of 2.6 mm/year (-0.4%) under the Industrious Ants scenario. This includes the increased water use as a result of the replacement of tree cover by agricultural land (around 0.8 and 0.9 mm/year on average for pasture and cropland each). In combination with the reduced interception of occult precipitation by trees, this leads to an overall increase in the water balance of around 2.4 mm/year (+1.6%) for the whole of Kenya with changes visible in those areas where changes in land use are projected to take place (Figure 5).

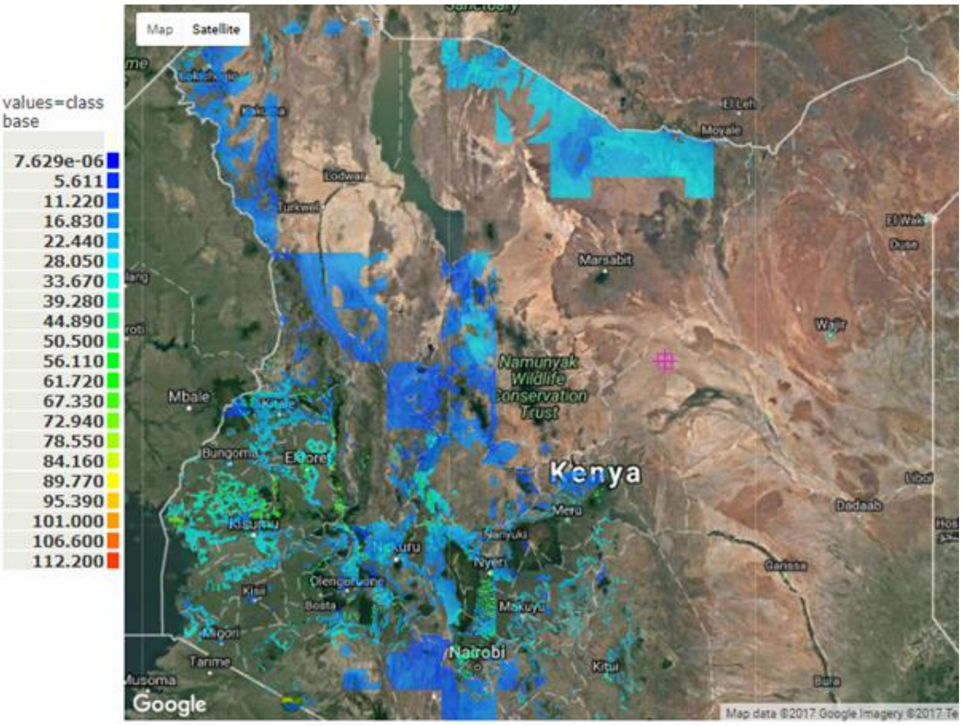


Figure 5 Increase in water balance (mm/year) between baseline (2005) and future (2050) for the Industrious Ants scenario with protection: http://www1.policysupport.org/userdata/NhQwfkvOxm

These changes in water balance result in increased runoff. Both overland flow and river flow are increased, which is particularly visible in the large rivers such as the Tana (Figure 6). Figure 6 only shows the change in river flow. In reality, of course, all this water does not run off and there will be more infiltration and soil storage which would potentially increase base flow in the low flow season, which will ultimately (at least on an annual basis) result in more flow.

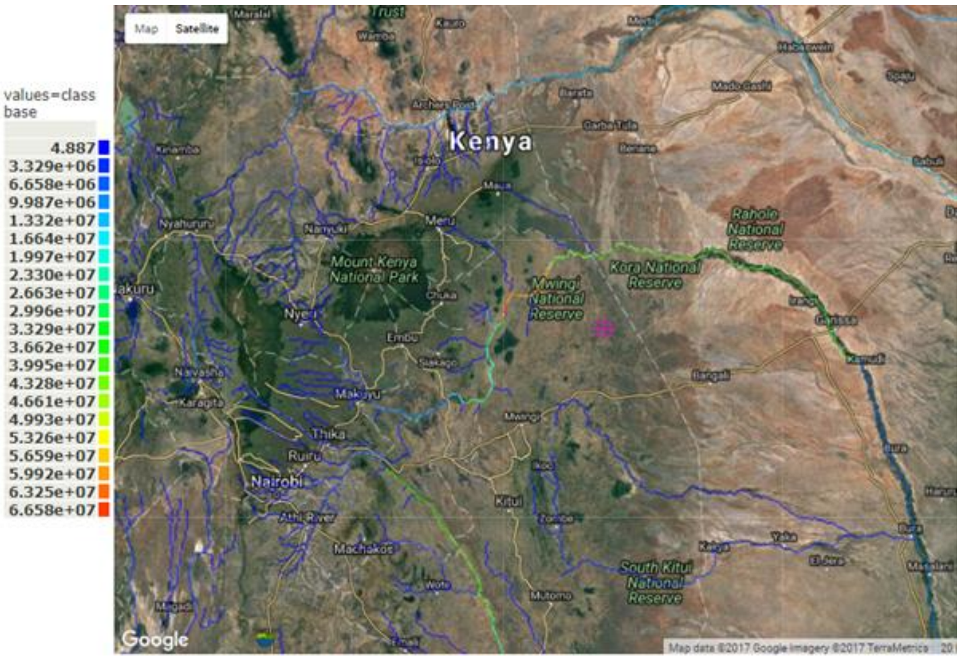


Figure 6 Increase in runoff (m3/year) between baseline (2005) and future (2050) for the Industrious Ants scenario with protection: http://www1.policysupport.org/userdata/mEPnbSC5oZ

The conversion of natural land to agriculture increases the potential pollution to water sources. The human footprint index increases on average with 0.7% but in some areas increases with more than 35% (Figure 7). This may lead important costs in terms of siltation of waterways, health problems due to pollution of water sources and water treatment needs.

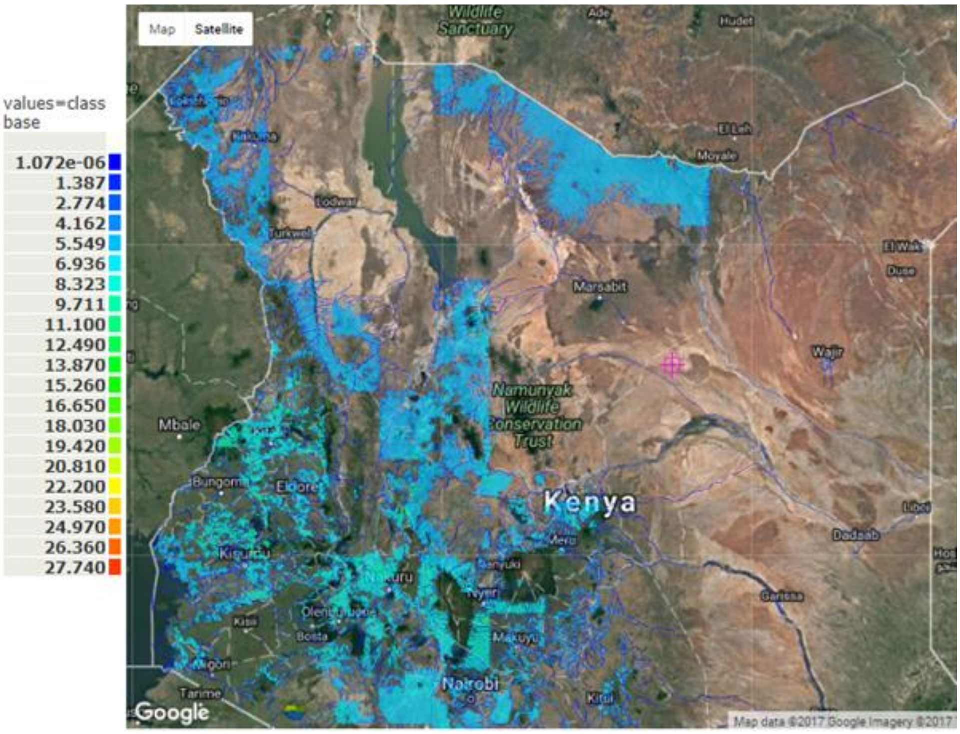


Figure 7 Increase in human footprint on water quality (% contamination) between baseline (2005) and future (2050) for the Industrious Ants scenario with protection: http://www1.policysupport.org/userdata/pTcrW35EKN

Hydrological services under climate change

Projected climate change (based on the RCP 8.5 emission scenario, which was also used for the crop modelling underpinning the land use model), results in increases in precipitation of about 84% for the whole of Kenya. Temperature under this scenario and model is projected to increase with 3.0 deg C, leading to increased evapotranspiration. However, the total increase in precipitation is much higher, therefore the net result on the water balance is an increase by around 420 mm/year for the whole country. Therefore, the projected impacts of climate change are much larger than the projected impacts of land use change alone (+2.4 mm).

Pollination services

Maps of the impacts of land use and human population density on local invertebrate pollinator richness were produced using the PREDICTS database records for samples that collected data on invertebrate pollinators in Tanzania and Kenya. Pollinator species richness in the cropped areas (see Figure 1) of western and south-central Kenya is relatively low compared to the pre-human situation (Figure 8, a) according to this analysis.

Patterns of future projected decline in species richness of pollinators appear to be correlated with the expansion of crop and pasture lands (Figure 8, b). Modelled historical and futures pollinator declines seem associated with the expansion and potential intensification especially of staple crops such as cereals (see Figure 1, Figure 9, Figure 10). These crops are not pollinator-depended and so are unlikely to suffer, but the declines in pollinator species may affect other crops such as coffee, tea, fruit and vegetables (e.g. avocado, kale, pumpkin, okra) which are pollinator dependent or whose production is enhanced with insect pollination. These crops are important for income and for nutritional diversity.

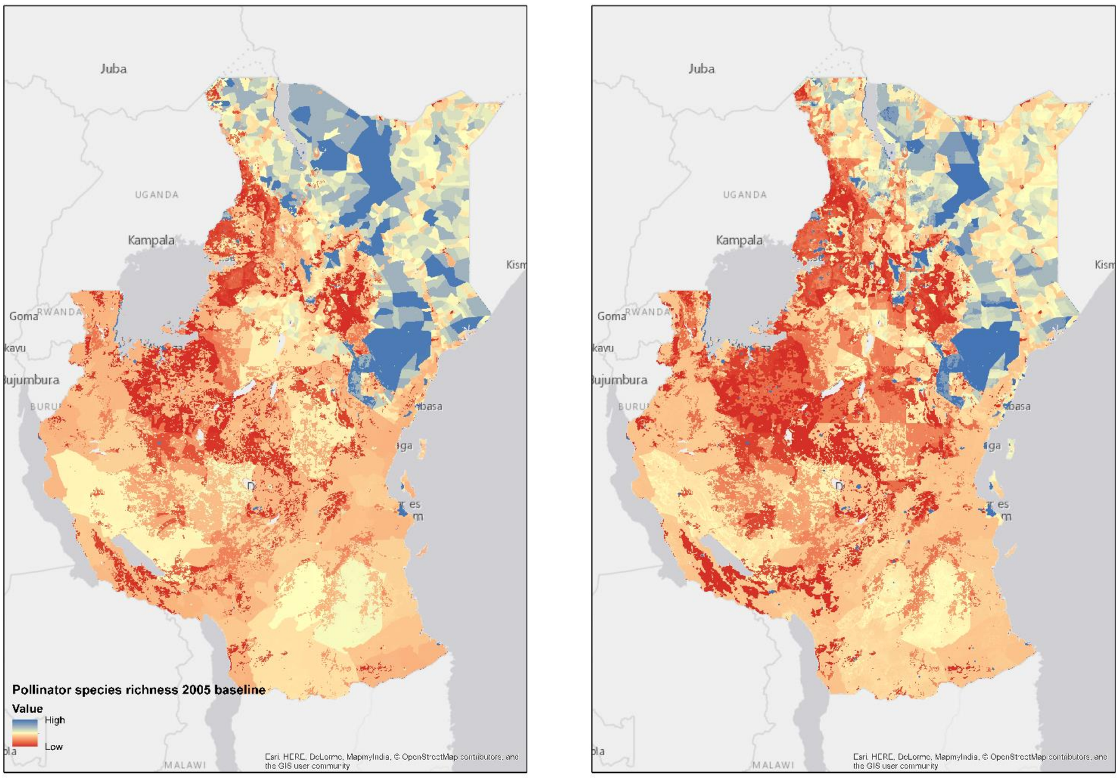


Figure 8 a). Pollinator species richness at 2005 baseline, b) Change in pollinator species richness predicted by 2050 using the Industrious Ants scenario. The 2005 baseline map shows community assemblage relative to that of a landscape assumed to be composed of entirely unused primary vegetation (Newbold et al. 2015)

Where might there be potential to increase productivity and therefore reduce demand for land conversion?

This section presents the results of an analysis of the potential implications for biodiversity of different scenarios for meeting cereal demand in Kenya (maize, wheat, sorghum, millet and irrigated rice – no data for rainfed rice). These scenarios are not related to the East African scenarios used in the analyses described above as they build on a different piece of work so it was not feasible to align at this scoping phase. A species richness indicator was used as a proxy for biodiversity (as opposed to the metric used earlier). This analysis is based on the premise that higher on-farm yields of staple crops could reduce the pressure for further expansion of agriculture on land currently not used for agriculture and avoid negative impacts on biodiversity and ecosystem services. Yields for most crops in Tanzania are lower than their potential: there is a so-called yield gap.

In rain-fed systems, the yield gap is defined as the difference between the actual yield of a crop and its estimated water-limited potential yield. For irrigated systems (such as rice) there is no water limitation. In this study, the biophysical potential for closing the yield gap is based on two variables: (1) the relative yield gap (3 classes), and (2) the temporal coefficient of variation of water limited yield potential (2 classes). The first variable indicates the potential for closing yield gaps, the second indicates the risk of low yields; both of which are likely to influence farmer’s decisions on whether to invest in yield increasing inputs or practices. These variables are combined into six classes and mapped using spatial data on crop distribution and climate-driven suitability (Van Wart et al., 2013).

In the analysis it was assumed that if the gap is large and the risk is low then farmers have an incentive to invest in practices to close yield gaps. This may reduce the pressure on further expansion of agriculture onto other land uses.

In both scenarios a similar increase in demand was used as the main driver of change, but different assumptions were made about the extent of yield gap closure. Scenario 1 (S1, Figure 9), assumes no change in actual yield, whilst scenario 2 (S2, Figure 10) assumes yield gap closure to a yield gap of 50% where risk is low, and 0% where risk is high. Figure 9 and Figure 10 show the change in harvested area (within already cultivated regions) required to meet this future demand under the two respective scenarios.

Assuming increased demand for cereals and no closure of the cereal yield gaps (S1) Western Kenya would need to expand the area cultivated to cereal crops (Figure 9). Some of the areas with greatest number of species—such as the central highlands of Kenya—do not experience great changes in harvested area, but this is mainly due to the current low levels of cultivation of cereals in these areas.

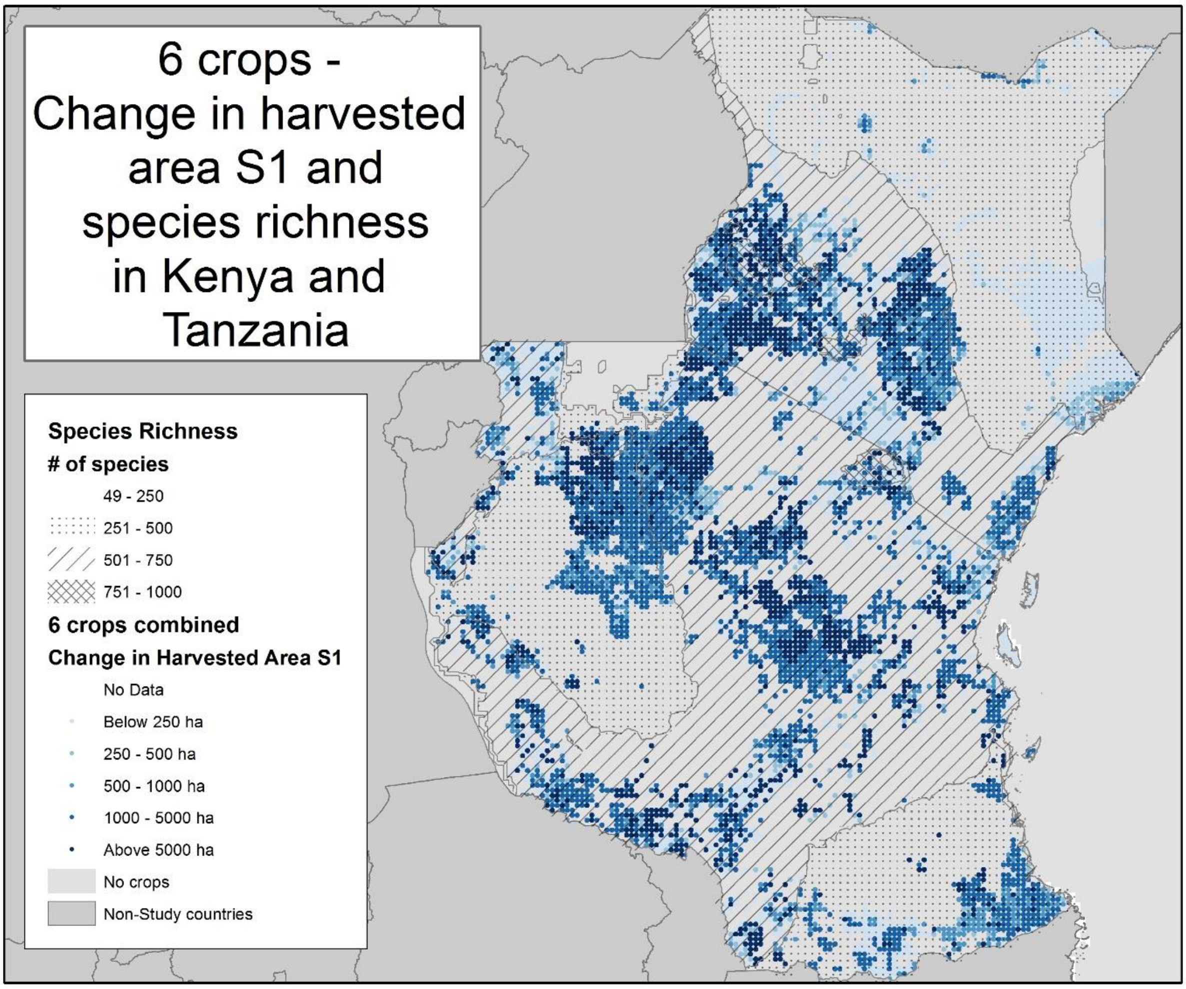


Figure 9 Species richness and changes in cereal crop harvested area in Kenya and Tanzania under scenario S1 (Data source: WCMC 2017; GYGA 2017; GADM v2.8; SPAM 2005)

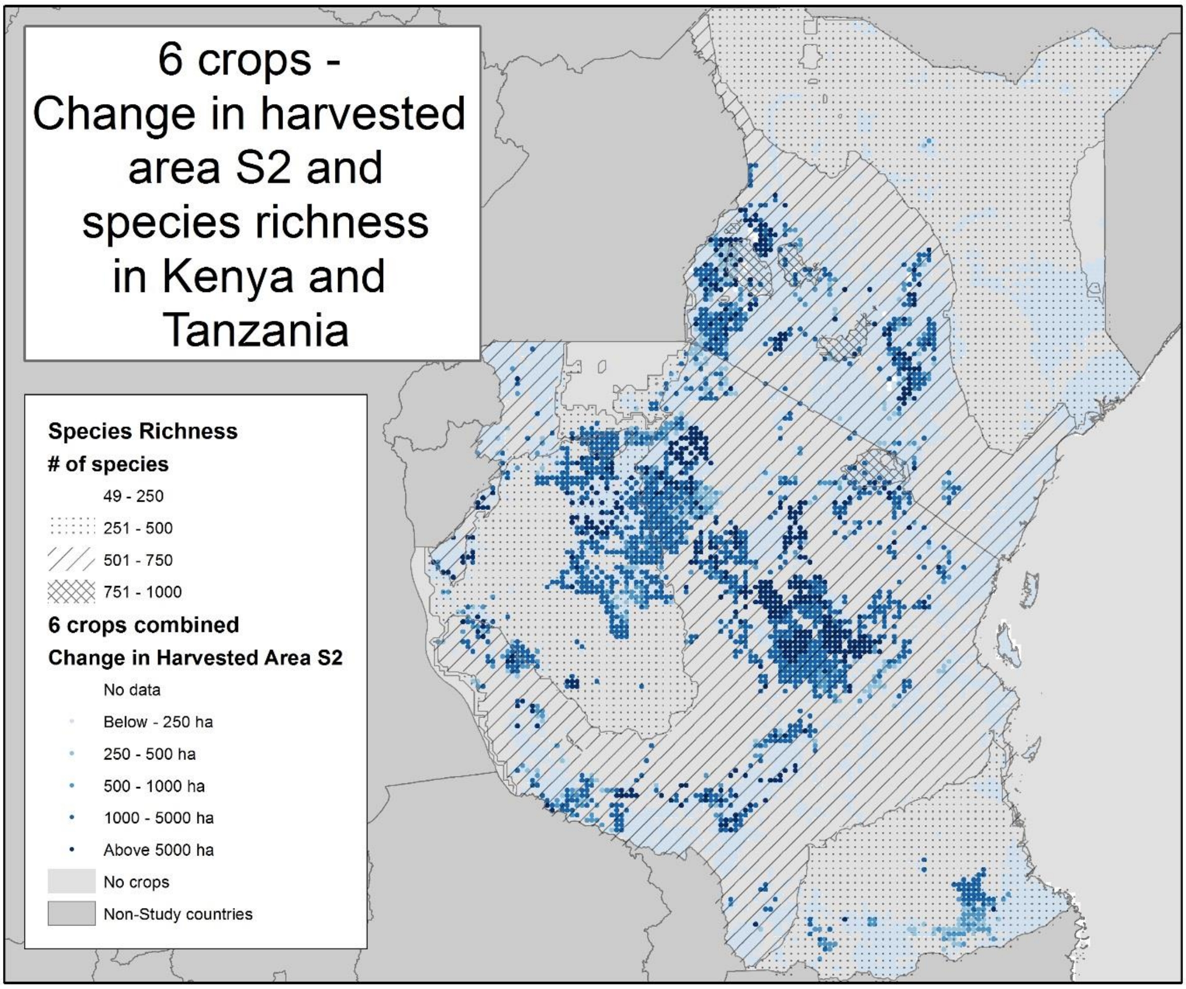


Figure 10 Species richness and changes in cereal crop harvested area in Kenya and Tanzania under scenario S2 (Data source: WCMC 2017; GYGA 2017; GADM v2.8; SPAM 2005)

The areas with the biggest differences between the scenarios are in the western and central highlands of Kenya (Figure 9 and Figure 10). These are the low risk GYGA TEDs where farmers are hypothesized to invest in practices to close yield gaps, such as fertiliser application and adoption of higher yielding cereal varieties. Areas where there is no information on yields will also show large differences due to the assumption of yield increases that match demand.

In both scenarios there are some locations that will be unable to meet demand due to a lack of land. It is difficult to exactly determine all of these areas because many parts of Kenya enjoy a bi-modal climate allowing two cropping seasons per calendar year.

This study found no relationship between the biophysical potential for closing the yield gap and levels of species richness. Variation may have been masked due to various data limitations. In this study the implications of a potential change in agricultural intensity was considered in light of a measure of "current" biodiversity, not biodiversity change due to the change in land use or management. The analysis would likely benefit from using a range-rarity biodiversity index or an indicator derived from a more taxonomically representative database (such as the PREDICTS) linking species presence with land-use, instead of a simple overlay of current species ranges with harvested areas.

However, perhaps a more fundamental question is the relationship between agricultural intensity, intensification of the system to close the yield gap and the impacts at a local level on biodiversity and ecosystem function provision. And these impacts may vary. For instance, technologies and practices focussed on balancing crop nutrient application with an emphasis on appropriate composition, quantity, placement, and timing of inorganic fertilisers are unlikely to have an adverse effect on biodiversity or ecosystem function provision in many agro-ecosystems in Tanzania (Godfray and Garnett, 2014), but when complemented with other technologies—such as grain legumes—could have a more beneficial impact (Snapp et al., 2010). The corollary of this situation can be found in those areas where investments in fertilisers carry a higher risk due to large variations in yield due to climatic variability. These areas already have a greater intensity of cultivation of cereals, so solutions to reduce risk (e.g. micro insurance schemes) will be needed to increase the likelihood of investments in technologies to sustainably close yield gaps.

Conclusions

- Modelled historical impacts of land use change on biodiversity and ecosystem services (e.g. pollination) show that areas where negative impacts are projected to be most likely in the future, have already been strongly modified by historical land use.
- Climate change is projected to have major impacts on agricultural production in Kenya. The results show general impacts, though effects will vary locally and for different crops or livestock production systems. It is important to identify these potential affects and devise an agricultural development strategies that are guided by these broad patterns and able to adapt to changing local conditions. Kenya has recently developed a Climate Smart Agriculture (CSA) Strategy which seeks to address these impacts[1].
- The results also show that it is important and possible to identify spatial patterns of likely threat and pressure that are consistent under different socio-economic and climatic futures as this allows the identification of areas to prioritise for further investigation and action. Some current assessments of Africa's ability to produce enough cereals for its own population now and in the future incorporate yield gaps closure in scenarios but assume a uniform closure. This is unlikely to be the case as many factors influence this. Similarly, biodiversity, ecosystem functions and services (i.e. beneficiaries) are not evenly distributed. The potential for and benefits of intensification in terms of land spared and impacts on ecosystem service and biodiversity (assuming a land sparing strategy) are therefore likely to vary in space, and over time with climate change.
- It is important to consider different types of ecosystem services separately, as there may be trade-offs among them. Most notably among commodity provisioning (e.g. agriculture production) and non-commodity provisioning (e.g. wild food, fuelwood) or regulating ecosystem services (carbon sequestration, water regulation). These trade-offs may operate at different scales.
- The results also highlight the importance of considering the landscape in which certain types of agricultural production takes place, as there may be negative feedbacks affecting production downstream, for example by affecting hydrological processes leading to infrastructural and health costs, or by affecting other crops. The latter is illustrated in particular through the potential implications of projected large scale cereal expansion to meet staple food demands for pollinator-depended cash crops that are important for local livelihoods as well as for crops that

[1] The results of the scenario analyses presented here were used in a scenario-guided review of the implementation framework of the CSA strategy, in order to assess its feasibility and improve its robustness in the face of future uncertainty. This process led by the Kenyan agricultural and environmental ministries with support from UNEP-WCMC and the CGIAR programme on Climate Change, Agriculture and Food Security (CCAFS) resulted in a policy memo that fed directly into national level implementation discussions.

are important for their nutritional values. It is important to better understand these interactions and their implications for food security.

- A fundamental question is the relationship between agricultural intensity, intensification of the system to close the yield gap and the impacts at a local level on biodiversity and ecosystem function provision. Some areas of high yield gaps with relatively low risk (from weather variability) for investments in closing them, also correspond to areas with high levels of ecosystem function, where food production, according to this study, is projected to increase at the expense of wild provision and regulating functions associated with forest habitats. In these areas, population densities (and therefore beneficiaries of these services) are relatively high and expected to remain so.
- Critically, the results reinforce the urgency of the need to boost agricultural production by increasing yields, whilst putting in place appropriate incentives and regulation to avoid expansion of cropping or grazing into forest or grass/shrubland areas that hold important biodiversity and provide ecosystem services, including to agriculture, that support local livelihoods and national economies.
- Finally, the relationship between agricultural intensity, technologies and practices that support intensification of production systems to close yield gaps and the impacts at a local level on biodiversity and ecosystem function provision need further investigation. Yield gap calculations and analyses of the potential to close them (and how), are needed for more climate zones and crops. Also analyses of potential trade-offs with biodiversity and ecosystem functions would benefit from more refined indices.