

Ecological Forecasting Using Geospatial Analysis: Example From Kenya (2019)



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INTRODUCTION

1. Objectives

1. This study has three objectives. The first is to demonstrate the utility of remote sensing data and tools for monitoring changes in land cover and estimating the amount of aboveground carbon stored in an ecosystem. This helps establish a baseline and assess changes since implementation. The second goal is to use the drivers of local land change to forecast the land cover and amount of aboveground carbon in the Protected Areas in the future (2020 and 2030). The third objective is to assess the sustainability of the MKEPP GEF project described below, in the Mount Kenya ecosystem which was completed in 2012.

2. Background

2. The Agriculture, Forestry, and Other Land Use (AFOLU) sector contributes to about 24 percent of anthropogenic GHG emissions or about 10-12 Gt of CO₂ equivalents per year (Smith et al. 2014). Land use change which includes deforestation is one of the main drivers of biodiversity loss, land degradation and cause of greenhouse gas emissions. GEF support to address these issues in agriculture and land use systems include multi-focal area (MFA) projects, sustainable forest management, restoration activities, and through integrated approaches in GEF 7 including food systems, Land Use and Restoration Impact Program, and the Sustainable Forest Management Impact Program.

3. GEF tracking tools have been employed to monitor progress in achieving outcomes and impacts. For instance, in the land degradation focal area, the global environmental benefits are tracked through indicators such as *land cover, avoided emissions and carbon sequestration*. A tool that has been employed by GEF agencies to capture the carbon benefits in land degradation, and in multi focal projects is EX-ACT (EX-ante Appraisal Carbon-balance).

4. EX-ACT is a land-based accounting system developed by FAO. It is a useful cost-effective tool to measure carbon stocks and stock changes per unit of land and requires minimum data inputs. The tool is helpful for estimating and prioritizing project activities especially in terms of economic and climate change mitigation benefits.

5. Although easy to use and deploy, tools such as EX-ACT has certain limitations. It is not spatially explicit, and does not account for the contextual factors driving land use and land cover change. The main input for the models is area and type of land cover pre intervention mainly derived from official records or information from satellite based classified images. The main output of the tool is limited to carbon balance (GHGs) expressed in terms of tCO₂e/ha.

6. A spatially explicit ecological forecasting approach which employs a tool, such as the Land Change Modeler used in this paper can help address and complement appraisal systems

such as Ex-ACT. The main input of the spatially explicit ecological forecasting models are land cover maps. These maps can be easily generated from processed satellite data.

7. This paper presents a practical application of an ecological forecasting tool which uses geospatial analysis. It demonstrates the utility of ecosystem modelling tools in forecasting changes in land cover that could be applied ex-ante to set realistic targets and thereby estimate expected returns on GEF investments. The paper employs a methodology that helps quantify land cover change and aboveground carbon estimates for multiple time intervals and develops projections for the future. This study builds on IEO’s previous work on evaluating the effectiveness of PAs and their impact (GEF IEO 2015), and the value for money analysis of GEF investments which measures carbon sequestration in GEF land degradation and biodiversity projects (GEF IEO 2016, 2017).

3. Study Area: The Protected Areas in Kenya

8. Agriculture and public or private development projects drive majority of deforestation in Kenya (KFS, 2010). The country continues to lose an average of 12,000 hectares (ha) of forest and 33,500 ha of open woodland per year, which equates to an annual loss of 2 million metric tons of carbon (KFS, 2010). This is consistent with the overall observation that in the tropics and subtropics, agriculture is the primary driver of forest loss, with local subsistence agriculture accounting for up to 33% of all conversions and large-scale commercial agriculture accounting for an additional 40% (FAO, 2016).

9. To combat deforestation and biodiversity loss, the GEF has invested in the creation and maintenance of Protected Areas (PAs) while also supporting projects outside of PA systems. In Kenya, GEF projects have supported interventions in and around nineteen PAs that could be precisely identified through the review of project documents. The PAs span a total area of 5,035 km² covered a wide range of land cover types and designations. This study examined twelve of the terrestrial PAs (Figure 1; Table I) consisting of two national parks, five forest reserves, three National Reserves and one Marine national reserve and one Community Conservancy. These PAs cover a wide range of land cover types including montane forests, coastal mangrove forests, deserts, grasslands, and shrub. The largest PA is Mount Kenya NP (2,714.5 km²) and smallest is Mrima Forest Reserve (3.9 km²). The evaluation covered two-time periods: 1995-2016 and 2020-2030.

Table 1:PA information including name, designation, Landsat tile location, and size

PA Name	Designation	Path / Row	Size (km ²)
Arabuko Sokoke	Forest Reserve	166/62	6.0
Buda	Forest Reserve	166/63	6.7
Diani	Marine National Reserve	166/63	75.0
Gogoni	Forest Reserve	166/63	8.2
Kakamega	National Reserve	170/60	178.4

Lewa Wildlife Conservancy	Community Conservancy	168/60	222.6
Marenji	Forest Reserve	166/63	15.2
Meru	National Park	167/60	870.0
Mount Kenya	National Park	168/60	2,714.5
Mrima	Forest Reserve	166/63	3.9
Shimba Hills	National Reserve	166/63	192.5
Tana River Primate	National Reserve	166/61	169.0

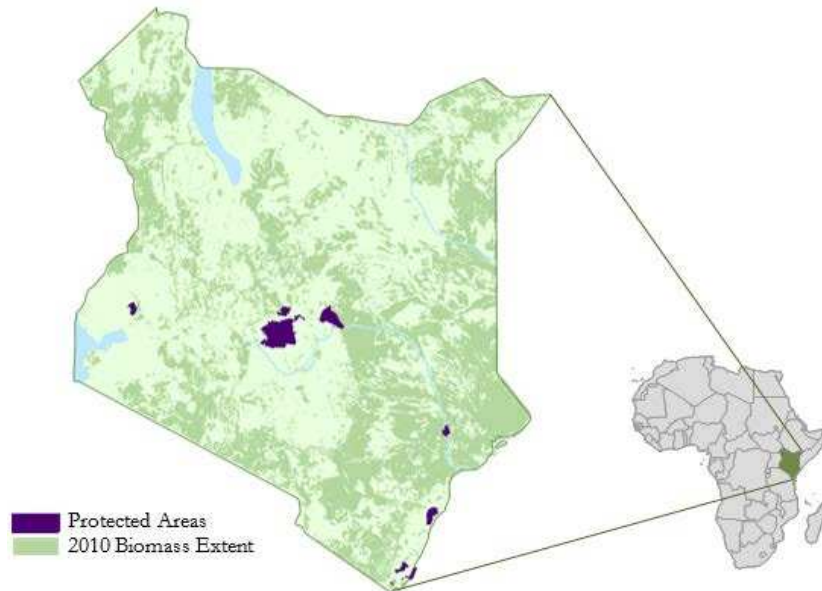


Figure 1: Study area map of the twelve PAs within Kenya included in the analysis

4. Study Area: Mount Kenya Ecosystem with a site visit for assessing sustainability

10. A detailed study was conducted for ground validation and sustainability in the Mt. Kenya area. The Mount Kenya ecosystem is contained within five counties (Nyeri, Kirinyaga, Embu, Tharaka-Nithi, and Meru) and has diverse ecological zones (Gichuki, 1999). Indigenous closed-canopy forests of the lower slopes transition to sparsely-vegetated landscapes including upper montane forests, heathland, and chaparral as the elevation increases (Figure 2). The southeastern portion of the mountain also contains a wide band of bamboo forests and hosts ideal conditions for tea cultivation along a significant portion of the mountain’s lower slopes (Ojany, 1993). While some agriculture and small communities exist on the fringes of the reserve, conservation laws have prevented additional encroachment of developed land into the PA.

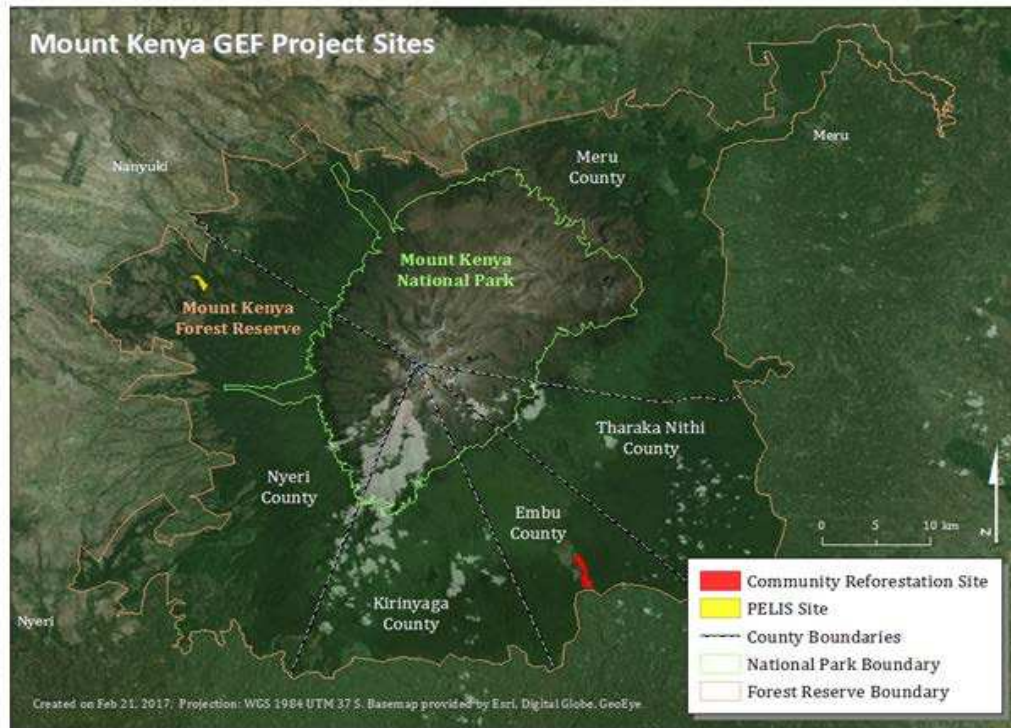


Figure 2: Map of Mount Kenya with MKEPP and the visited Community Forest Rehabilitation site and PELIS Project site highlighted

11. In addition to its rich biodiversity, Mount Kenya also includes the main water catchment area in the region. Kenya's largest river, the Tana River, as well as the Ewaso Ng'iro River, are both sourced by the rainfall, snow, and glacial melt coming from the mountain (Gichuki, 1999). This ecosystem is therefore a tremendously important resource that supplies water to approximately 95% of Nairobi's population and generates nearly 50% of the country's hydroelectric power (TNC, 2015). Protecting this important watershed has been a priority for the Kenyan government through balancing competing interests for hydroelectricity, urban consumption, and agricultural use.

5. GEF project interventions in the Mt. Kenya Ecosystem

12. The Mount Kenya East Pilot Project for Natural Resource Management (MKEPP), a full-sized project has taken place in the Mount Kenya ecoregion since 2000; an integrated ecosystem management plan enacted by the International Fund for Agricultural Development (IFAD) between 2002 and 2012. MKEPP combined biodiversity and capacity-building initiatives, with the goal of achieving more equitable and sustainable use of resources and enhanced conservation (GEF, 2012). Within MKEPP, the Plantation Establishment and Livelihood Improvement Scheme (PELIS) program has been established in the Mount Kenya ecosystem. PELIS is a system whereby the Kenya Forest Service (KFS) coordinates with community forest

associations (CFAs) to grant forest-adjacent communities the right to cultivate agricultural crops during the early stages of forest plantation establishment, generally a period of three to four years (Kagombe, 2014). The main objectives of PELIS are to improve livelihoods, boost participatory forest management, and restore forest cover. The most recent project intervention in the area is the ‘Establishment of the Upper Tana Nairobi Water Fund (UTNWF)’ (GEF ID 9139), a full sized GEF-6 project within the Food Security Integrated Approach Pilot (IAP).

13. **Upper Tana Catchment Natural Resources Management Project (UTaNRMP):** This is an eight-year project (2012–2020) funded by the Government of Kenya, IFAD, Spanish Trust Fund, and local communities. This was not funded by the GEF but builds on the MKEPP project. The aim is to improve the sustainability of livelihoods and resource management in the project area. Specifically, implementation will be carried out through four main components: Sustainable Water Resources and Natural Resources Management, Sustainable Rural Livelihoods, Community Empowerment, and Project Coordination and Management (IFAD, 2013). The MKEPP project is being scaled up to cover the UTaNRMP project area, starting with continued work on the five MKEPP river basins and eventually expanding to twelve high-priority river basins and twelve other river basins in the Upper Tana catchment.

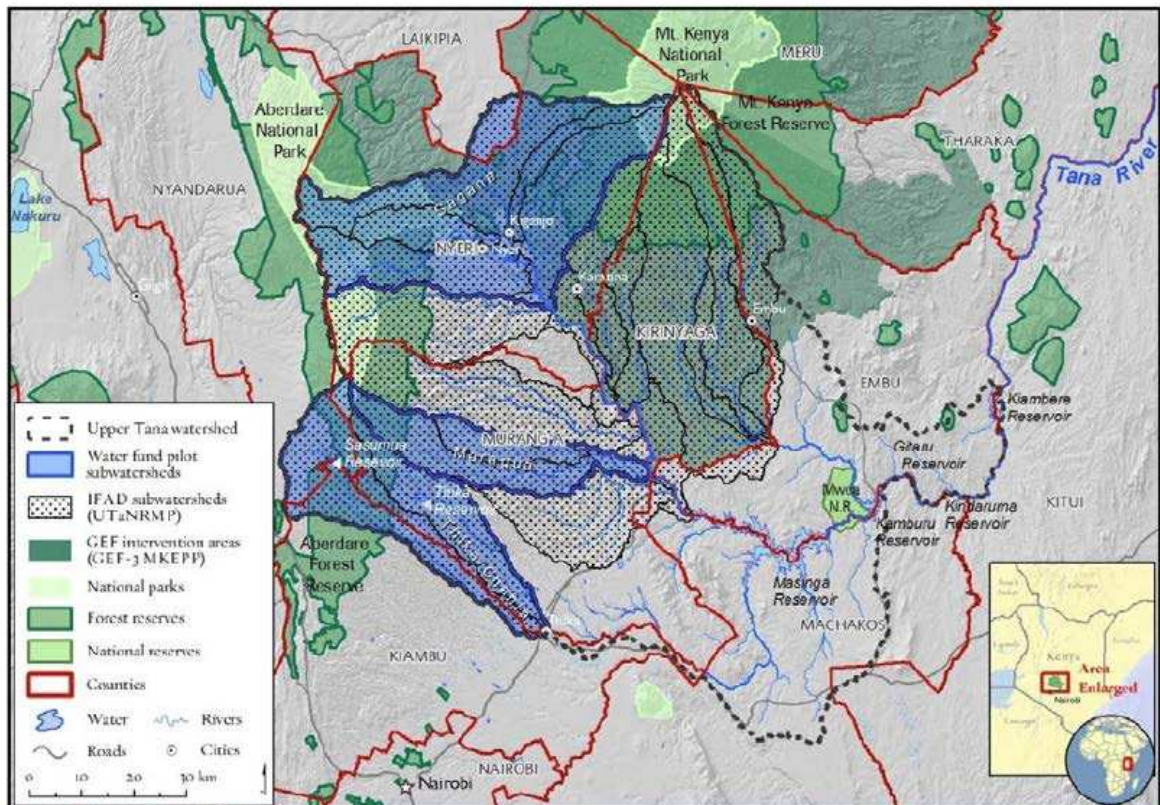


Figure 3: Map showing the overlap between project intervention areas of the GEF MKEPP and IFAD Upper Tana Catchment Natural Resources Management Project (UTaNRMP) projects; Map Credit – The Nature Conservancy

DATA AND METHODS

14. This study uses land use change analysis, ecological forecasting and ecosystem service estimation in terms of carbon stocks. Carbon stock is calculated using the national and regional coefficient as per the IPCC guidelines. The study uses Kenya as a case study to show land cover changes in GEF supported protected areas, and estimate the future land cover and carbon sequestration benefits for Aichi 2020 and 2030 the SDG goals. Additionally, a mixed methods approach combining remote sensing with field validation visits to project sites around Mount Kenya provide in-depth review of the GEF-funded projects at multiple spatial and temporal scales. The GEF- IEO partnered with the NASA DEVELOP team housed at Goddard Space Flight Center to conduct this assessment. This paper did not look at the ex-ante impact of the projects which had just began implementation.

1. Data

15. The remote sensing analysis primarily utilized NASA Earth observations to assess the effectiveness of PAs throughout Kenya. Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI Level 1 products were acquired through Google Earth Engine for the study period of 1995–2016 (Table 1). Landsat images are suitable for our study because of the long historical archive, open availability, and adequate spatial resolution to analyze both large and small PAs. Google Earth Engine was used for both data acquisition and analysis as it is a cloud computing system that is free for non-commercial use. Freely available ancillary datasets were used as driver variables to project future land cover changes. These included climatic variables (temperature and precipitation), roads and waterways, human and livestock density estimates, and digital elevation (Figure 4). Full sources for the ancillary driver variables listed in Table II.

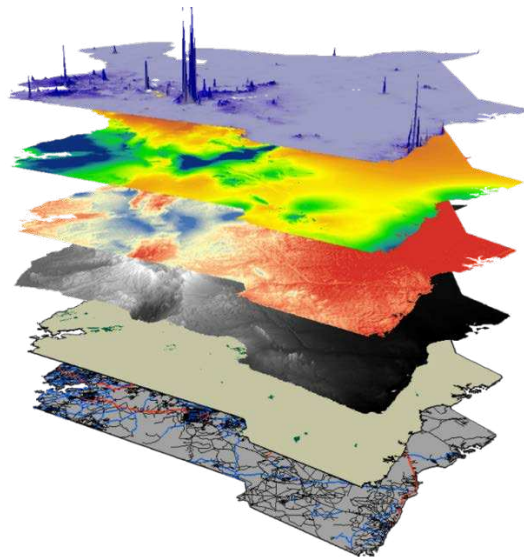


Figure 4: Figure showing the driver variables to model the potential for future changes in the study area. These variables included precipitation, temperature, population density, and proximity to agriculture, roads, and rivers. Data shown from WorldPop, WorldClim, NASA SRTM, FAO, and openstreetmap.

Table 2: Data sources for ancillary driver variables

Data	Source	Citation
Climatic: Temperature Precipitation	WorldClim	Hijmans et al., 2005
Roads and Waterways	OpenStreetMap	OpenStreetMap contributors, 2016
Population Density	WorldPop	Linard et al., 2012
Livestock Density: Sheep and Goats Cattle Chickens	FAO	Robinson et al., 2014
Digital Elevation Model	SRTM	NASA JPL, 2013

16. In place of *in situ* data regarding land cover types in each PA, high resolution commercial imagery in Google Earth Pro was utilized in the creation of training and validation sites for the land cover classifications. Landsat Top-of-Atmosphere reflectance products were processed in Google Earth Engine to remove clouds, cloud shadows, and water bodies (Zhu & Woodcock, 2012). All vector datasets were converted to 30 m resolution raster datasets to match the spatial resolution of the Landsat imagery. Similarly, other raster datasets were rescaled to the same spatial resolution as Landsat imagery using resampling tools in TerrSet and Esri ArcGIS.

17. Using satellite-based Earth observations a time series of regionally-specific land cover maps of the PAs were produced to provide a historical baseline of aboveground carbon estimates. With the classified images as a reference, land cover change and aboveground carbon estimates were quantified for multiple time intervals between 1995 to 2015, and projections for future land cover in each of the PAs were created. Field validation was carried out in the Mount Kenya ecoregion in January 2017 and largely consisted of visiting the interventions sites, interviews with key informants, project partners, participants, and community members (Figure 5)



Figure 5: GEF Forest rehabilitation site, showing rapid growth of vegetation since the project was completed

2. Methods

Land Cover Analysis

18. PAs were classified using regionally-specific training and validation points created in Google Earth Pro. Land cover classifications were performed in Google Earth Engine using Classification and Regression Tree (CART) and Random Forest classifiers. The best performing classifier for each PA was selected and the resulting land cover map was included in later analyses. A visual representation of the remote sensing methodology can be seen in Figure 6.

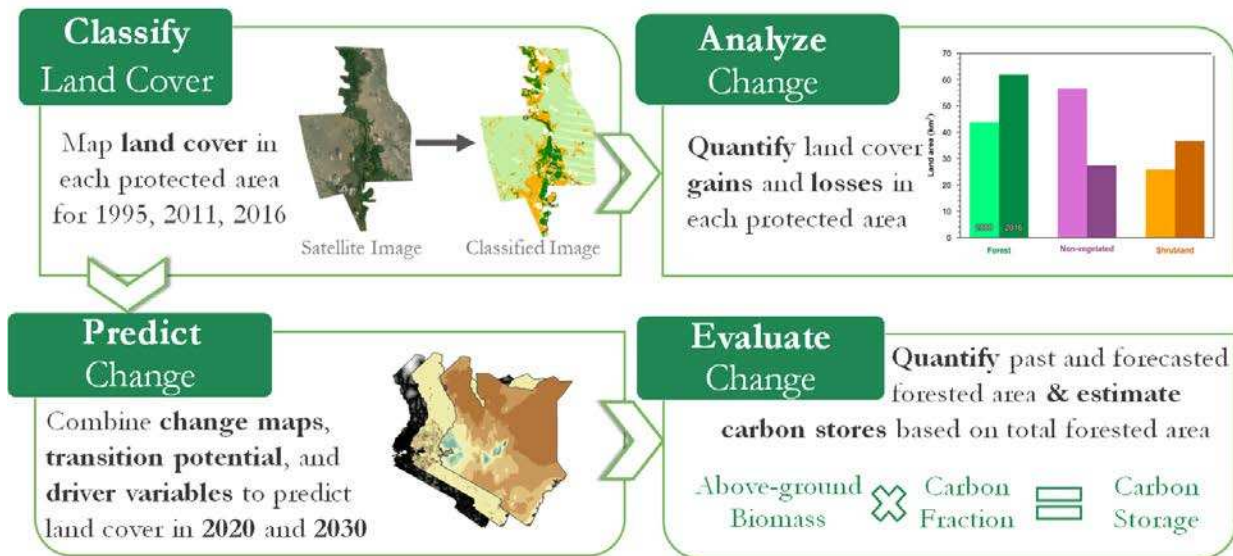


Figure 6: Remote sensing methodology for evaluating land cover and carbon change in PAs

19. TerrSet's Land Change Modeler (LCM) was used to evaluate change detection. It is useful for Land Change Analysis including for generating graphs and maps, estimating gains and losses, and net change. LCM is used for modelling land transition in the future and for assessing forest conservation strategies and policies such as REDD+.

20. Within LCM, Multi-Layer Perceptron (MLP) was used to evaluate the relationships between driver variables and the land cover changes. This neural network comparison is used to understand the historical rates of change, and generate transition potential maps. Models were tailored to each PA by eliminating the least influential variables until peak predictive power was achieved. After each model was trained, LCM's Markov Chain Projection was used to incorporate past rates of change and project future rates of change. These rates of change were applied to the transition potential maps to create future projections of land cover change for the target years 2020 and 2030. Above-ground carbon, C_L , for each land cover class, L , was estimated using a function of the observed land area (in hectares), allometric relationships between land cover and biomass, and carbon fraction:

$$(1) C_L = (\text{Area}_L) \times (\text{Biomass}_L) \times (\text{Carbon Fraction}_L)$$

Units were as follows:

$$(2) \text{Mg } C_L = (\text{ha}) \times (\text{Mg dry matter / ha}) \times (\text{Mg C / Mg dry matter})$$

21. For most PAs, the amount of aboveground biomass by land cover class and carbon fraction were obtained from both the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land-Use Change and Forestry, and the IPCC Guidelines for National Greenhouse Gas Inventories (Penman et al., 2003; Eggleston et al., 2006). Where available, locally-specific values were used for areas such as in the Kakamega Forest Reserve and Arabuko Sokoke Forest Reserve (Table III).

Table 3: Land cover types and associated carbon stock estimates for each GEF Protected Area

Land Cover Type	Protected Areas	Above-ground Carbon Stock Estimate (Mg C)	Source of Estimate
Rainforest / Dense Forest	Kakamega, Lewa	173.3	Lung and Espira, (2005)
Shrub	Kakamega, Lewa, Meru, Mt. Kenya, Tana, Mrima, Marenji, Diani, Gogoni	22.8	Colgen et al., (2012)
Bamboo	Mt. Kenya	103.6	Teng et al., (2016)
Cynometra Forest	Arabuko Sokoke	35.0	Glenday, (2005)
Brachystegia Forest	Arabuko Sokoke	45.0	Glenday, (2005)
Mangrove	Diani	146.8	Jones et al., (2014)

Coastal Forest (Moist Tropical with Short Rainy Season)	Marenji, Mrima, Buda, Gogoni, Shimba Hills, Tana River	122.2	IPCC, (2013); Eggleston et al., (2006)
Montane Moist Forest	Mt. Kenya	89.77	IPCC, (2013); Eggleston et al., (2006)

Mount Kenya Ecosystem: Field validation and assessing sustainability

22. Field validation consisted of visiting the MKEPP and UTaNRMP project sites to validate the land cover findings, and meeting with stakeholders including KWS officials, KFS officials, Community Forest Association (CFA) members, IFAD staff, and conservation NGO staff as they have been involved in the project implementation and continue to work in the Mount Kenya Conservation Area. The team was briefed on key activities of the Mount Kenya project.

RESULTS

23. **Results demonstrate that overall there has been an increase in the amount of above ground carbon.** The Kakamega Forest Reserve, a moderately sized dense rainforest in Western Kenya and home to 380 plant species, experienced an *increase in aboveground carbon from 1995–2015*. This may be attributed to a regrowth of forest since the protections have been put in place and agriculture is being removed from the protected area. The Marenji Forest Reserve, a small coastal forest in southeastern Kenya, also experienced an increase in aboveground carbon from 1999–2016. Shimba Hills National Reserve, a moderately-sized coastal forest in southeastern Kenya, has experienced a slight decrease in forest and corresponding above-ground carbon. Mount Kenya Forest Reserve, by far the largest PA in the study, has also seen a decrease in aboveground carbon inside the perimeter of the PA. This was largely due to what appears to be agroforestry and agriculture but the decline has tapered off in recent years.

24. **The results from Land Change Modeler suggest that vegetated land cover has increased in the Kakamega Forest Reserve site between 1999 and 2015** (Figure 7). In Figure 7, the topmost shows the spatial distribution of forest, non-vegetated, and shrub for the two-time periods in the past, and projections for years 2020 and 2030. Within Kakamega, areas that were previously agriculture have been transitioning back to forest. Forested areas have noticeably expanded, particularly in the southern half of the forest reserve. Shrub has also expanded into previously non-vegetated areas along the western edge of the forest. The middle and the bottom panel shows an increase in vegetation productivity and above-ground carbon estimates in the Kakamega Forest Reserve increase throughout the study period and in projections for 2020 and 2030.

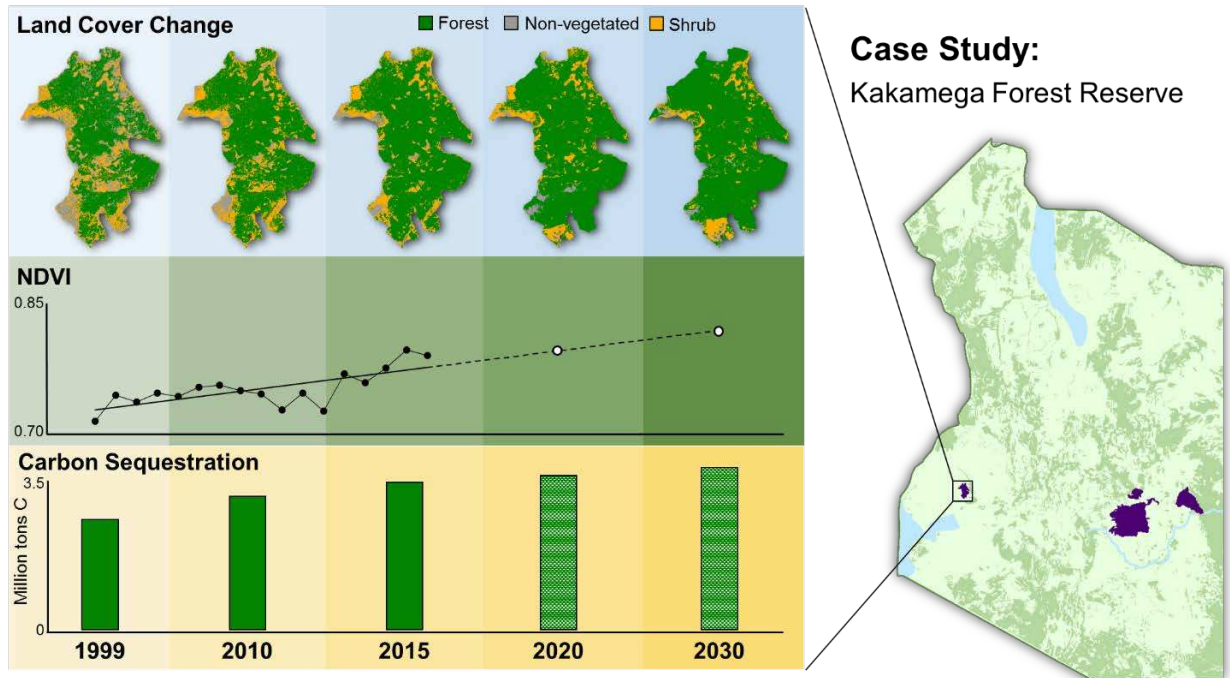


Figure 7: Land cover classifications for the reserve were produced using Landsat imagery, and show the progression of vegetation for 1999, 2010, and 2015. Projects for future land cover were accomplished using TerrSet Land Change Modeler, which factors in environmental driver variables to estimate future changes (top panel). The Forest Reserve experienced revegetation following GEF-funded projects. The annual average Normalized Difference Vegetation Index (NDVI - middle panel) illustrates the increasing reflectance of near-infrared light, consistent with increasing “greenness” of the vegetated surfaces. As reforestation occurs, more plant biomass is accumulated in the aboveground stocks. This carbon sequestration (bottom panel) reflects an additional co-benefit from the biodiversity project.

25. Several land change driver variables were incorporated to model the potential for future changes in the study area (Figure 4; Table II). In terms of the overall drivers, results showed that livestock densities (cattle, goats, and chickens) and distance to roads were not found to be influential, while distance to rivers and irrigated agriculture were. *Human population density was influential to the models where more communities surrounded PAs.* In remote areas, however, this impact was minor.

26. The Tana River Primate National Reserve shows a slightly different story (Figure 9). In this riparian forest in eastern Kenya, the landscape has four land cover types: forest, grass, shrub, and water. White regions represent cloud cover and scan lines that were masked from the analysis. In this study area, there are sporadic shifts in land cover, likely associated with flooding events near the Tana River. *Throughout the study period of 2000–2015 there are slight fluctuations in above-ground carbon estimates as shrub and forest area expand and contract.*

Grass was not included in above-ground carbon estimates as it is not generally considered a long-term carbon store.

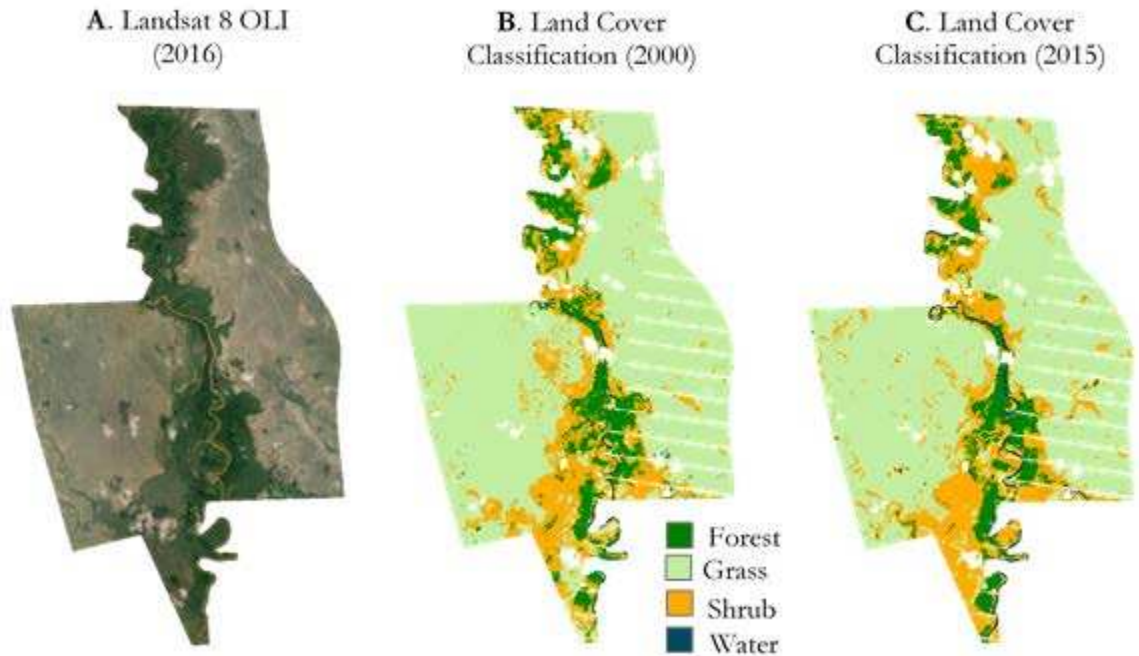


Figure 9: Land cover classification for the Tana River Primate National Reserve PA. Google Earth imagery of the PA was used to produce training sites for different land cover classes (panel A). Classified maps produce spatial distribution of land cover classes for 1999 (panel B) and 2015 (panel C).

27. **In the PAs included in this study, aboveground carbon estimates and projections are generally stable** (Figure 10). But few PAs experienced positive or negative change in the 15–20 year study. Some PAs such as the Kakamega Forest Reserve and the Marenji Forest Reserve experienced a moderate increase in forested area and corresponding above-ground carbon. In the Mount Kenya Forest Reserve (Figure 11) and the Shimba Hills National Reserve (Figure 10), moderate decreases in above-ground carbon were estimated and projected for 2020 and 2030. The observed decreases may be a result of pressure from developmental activities, agriculture expansion, and agroforestry within the PAs. In all cases, these estimates coincided with the years during and following GEF involvement in the reserve.

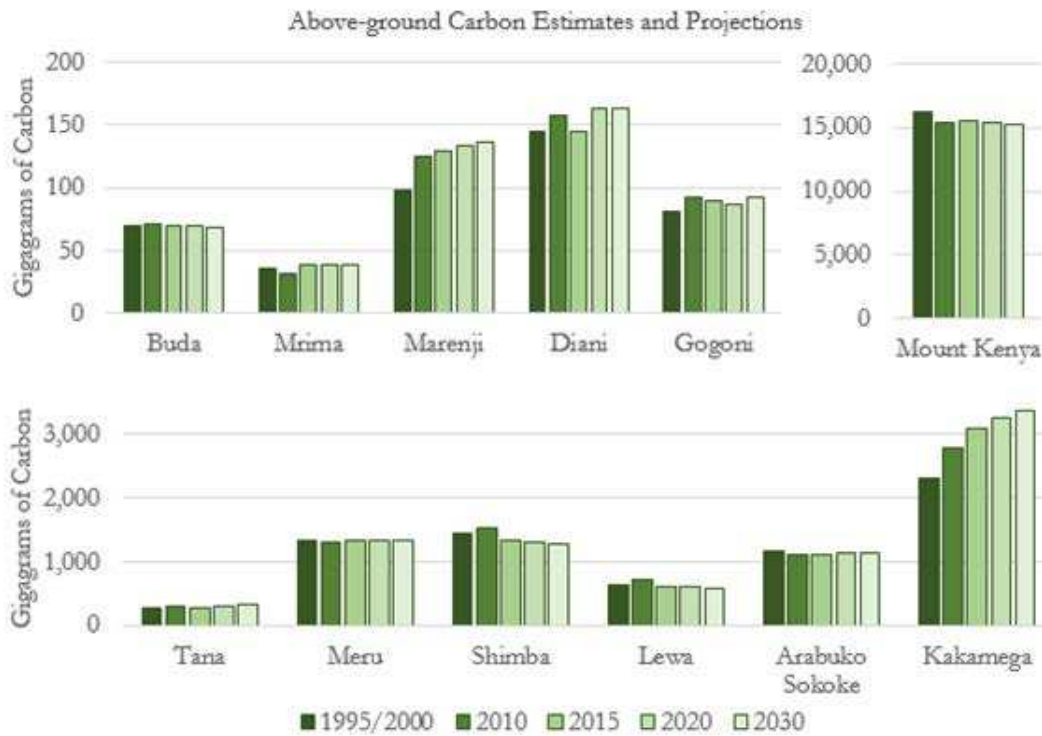


Figure 10: Above-ground carbon estimates and projections for all twelve PAs. Note the varied scales in each graph

Mount Kenya Validation Results:

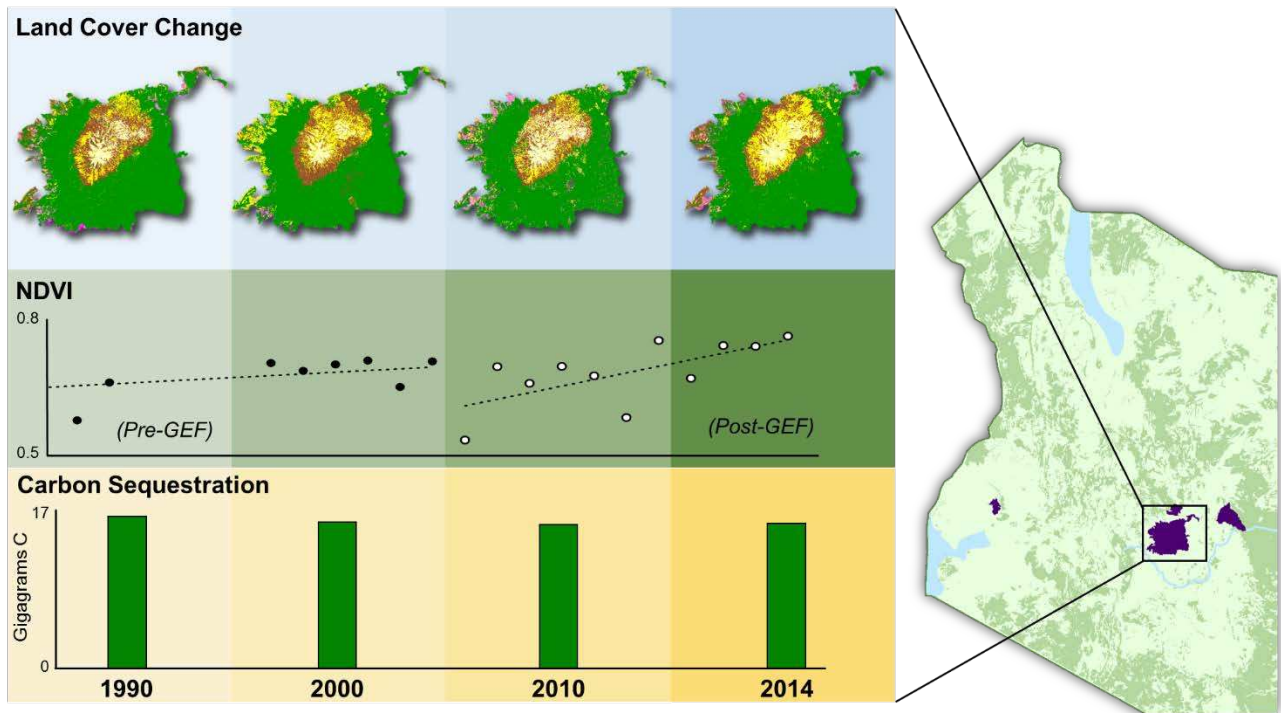


Figure 11: The Mount Kenya National Park and Forest Reserve

28. **Vegetation productivity increased over time (figure 11 and 12).** Land cover classifications for the reserve were produced using Landsat imagery, and show the progression of vegetation for 1990, 2000, 2010, and 2015 years. These dates show how land cover changes before and after GEF involvement in the Park (pre- and post- 2005; top panel). The Forest Reserve experienced revegetation following GEF-funded projects. The annual average Normalized Difference Vegetation Index (NDVI - middle panel) illustrates the increasing reflectance of near-infrared light, consistent with increasing “greenness” of the vegetated surfaces. The solid black points show the NDVI for dates before 2005, and the white points show the NDVI following GEF funding. We note the increase in the linear regression through the points, indicating increased greening of land surface. As reforestation occurs, more plant biomass is accumulated in the aboveground stocks. This carbon sequestration (bottom panel) reflects an additional co-benefit from the biodiversity project.

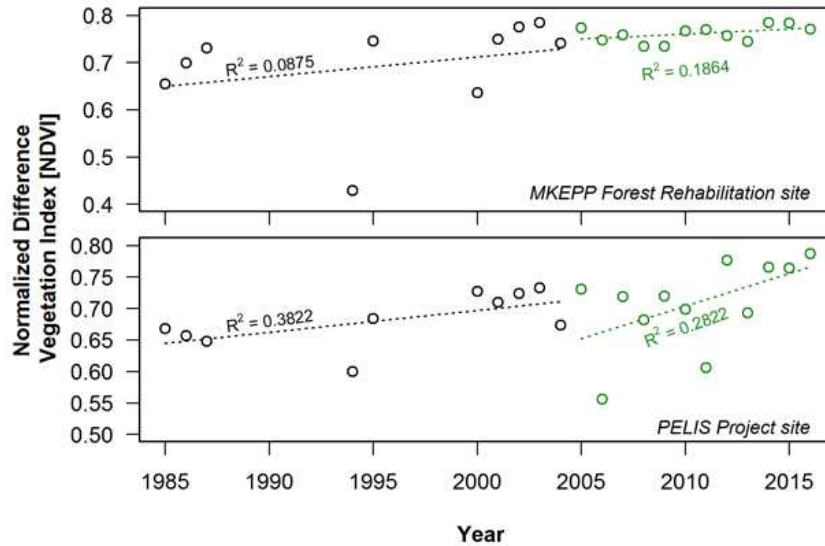


Figure 12: The Normalized Vegetation Index(NDVI) plot for the forest rehabilitation(top) and PELIS site(bottom) before GEF projects began and after completion. The NDVI values show positive trend indicating sustained forest growth.

29. The PELIS program (Figure 12 and 13) has been considered extremely successful in terms of income generation, food security, and tree survival rates. Visiting the location and comparing model outputs to observations helped understand the contextual factors. In alignment with the goals of GEF’s biodiversity focal area, more than 16,000 people were trained in tree nursery establishment and management, many of whom have adopted this as their livelihood. This program has been adopted in over fifteen counties across Kenya and has been used to reforest over 17,000 ha. At the Naromoru PELIS site, community members and staff from the KFS provided testimony on how plantations adopting agroforestry techniques helped increase community stability, as well as reforest regions on the western slopes of Mount Kenya. Other reforestation programs such as the MKEPP Community Reforestation efforts (seen in Figures 5) have also been successful in terms of sustaining regrowth. IFAD helped to establish an integrated management plan with 2,650 ha indigenous forest areas rehabilitated and 400 ha plantations established. Trainings were also conducted for ecological monitoring, water resource management, and wildlife patrols.

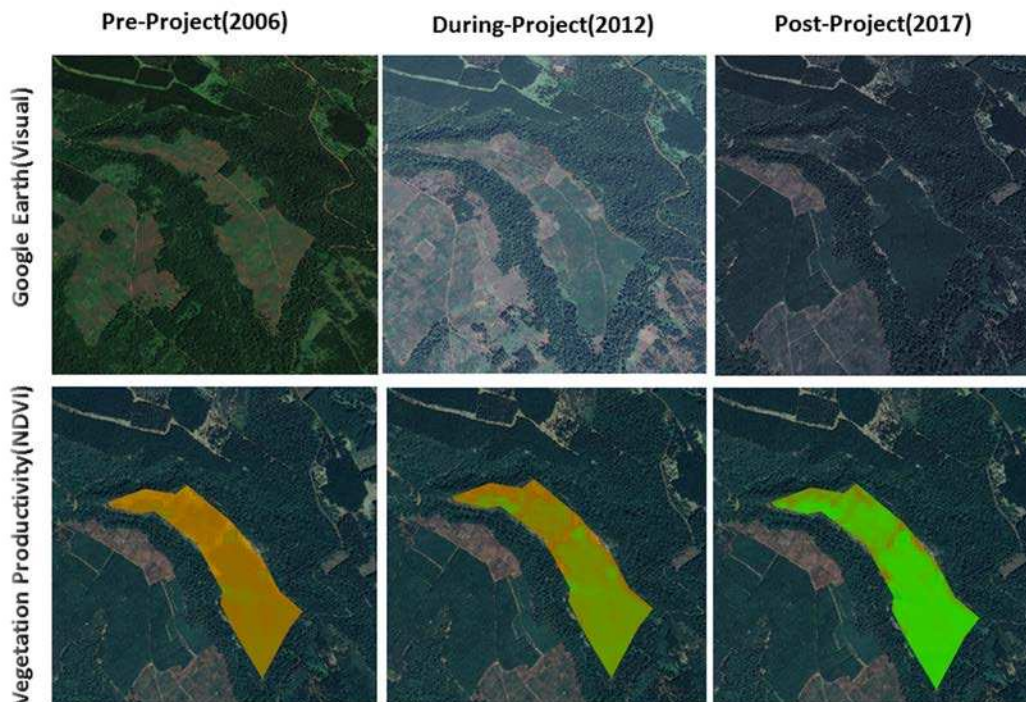


Figure 13: Optical(top) and NDVI(bottom) images before GEF projects began, during and after. Satellite data analysis shows sustained forest rehabilitation well past project closure in 2017

30. **Environmental and Socio-Economic Benefits were achieved with community engagement.** Long-term engagement with the community likely contributed to several tangible positive outcomes of the MKEPP and UTaNRMP projects, including reforestation and infrastructure improvements. Efforts to educate surrounding populations on sustainable forest management have reduced the willingness to engage in illegal activities such as logging or poaching. The construction of electrified fencing in multiple other sites (80 km total) has led to similar improvements in local livelihoods and attitudes toward government officials. One such fence installed in Kirinyaga’s Kangaita Forest has been instrumental in preventing disruptive wildlife from entering the surrounding communities and negatively impacting crops. Interviews with local farmers demonstrated that the security provided by the fences resulted in economic gains and improvements to their quality of life. The ability to sleep through the night without fearing for their crops, or to send their children to school without worrying about harm from wildlife, are significant outcomes of such infrastructure development.

31. Field visits with KFS staff in Kirinyaga County focused on highlighting several community interventions, such as reducing poverty by increasing food security, building capacity by establishing income generating activities, reducing human-wildlife conflict, and engaging communities in reforestation efforts. Small communities in the PA were supported through a variety of local initiatives within MKEPP including beekeeping and honey production, small animal agriculture, tree nursery creation and management, participatory forestry management,

and the formation of community-based cooperatives. One such community group had built a beekeeping business and created a niche in the local markets as well as registered their honey products for export. All groups testified to the benefits that the MKEPP had in reducing human-wildlife conflict and in boosting income generating activities.

32. **Institutional capacity and sustainability has been strengthened.** Through MKEPP, the KWS Information Research Center repurposed a historic National Park office into a center for geospatial and ecological research, with the goal of monitoring and tracking land and animals throughout the PA. Establishing a research center has helped focus efforts to create and maintain databases with spatial and non-spatial data, and record keeping has greatly improved. Datasets include research permits and affiliations, illegal wildlife trafficking and actions taken, human/wildlife conflict, elephant mortality, rainfall, and wildfires. Although only one researcher was trained in geospatial analysis through MKEPP, he has since shared his skills with others at the KWS Information Research Center and with research centers in other regions of Kenya.

33. Collaboration between the KWS and KFS have strengthened through the MKEPP project and have been maintained with strong leadership. NGO and governmental collaborations have also continued in the region, particularly between KWS and NGOs such as Rhino Ark and the Mount Kenya Trust. Both NGOs and various governmental agencies continue to interface with local community groups. These groups, which have historically avoided reporting illegal logging and poaching, have since gained a sense of ownership over both the fence around Mount Kenya National Park and Forest Reserve, as well as the natural resources contained in the ecosystem. Reports from communities around the park have increased since the initiation of the MKEPP project and have been sustained after the completion of the MKEPP project.

CONCLUSIONS

34. **Ecological forecasting using geospatial tools is useful in measuring Impacts and in ex-ante assessments.** The tool employed in this paper helps establish baselines, measure impacts and sustainability of interventions past project completion. It also demonstrates the possibility for carrying out ex-ante assessments of land cover change and associated carbon balance. This would help inform locations most appropriate for GEF interventions. Information generated through ex-ante assessments and ecological forecasting can be useful to address questions about land use change, natural capital valuation, biophysical measures and sustainability of ecosystem services. Given the low costs and reasonable estimates of land cover change and associated carbon, studies such as this are scalable. Estimation of ecosystem services such as carbon sequestration demonstrated through this study could be extended to other ecosystem services such as water provisioning, soil retention, etc.

35. **Geospatial methods and the biophysical indicators derived from earth observation can help monitor progress.** These methods can help harmonize the indicators, avoid double counting, measure co-benefits across the focal areas and help track progress towards Global Environment Benefits (GEBs) and the Sustainable Development Goals (SDGs). For instance, the three indicators used in this study 1) Land cover change 2) Land productivity (NDVI), and

3) Carbon stocks (change in above ground carbon) closely relate to the SDG 15.3 and the Land Degradation Neutrality (LDN) indicators, and also align with several core-indicators and sub-indicators proposed for the GEF 7.

36. **GEF interventions in the Kenya PAs have had continued success and provide evidence of sustainability.** Since the establishment of projects that support PAs began in Kenya in the 1990s, the PAs have had continued success in maintaining forest extent and preserving biomass. Of the twelve protected areas included in this study, most experienced little to no net change in aboveground carbon stocks over the 15–20-year study period. The modest changes in land cover and associated above-ground carbon are strikingly different from changes throughout rest of the region. While landscapes inside of PAs are relatively stable, the vast majority of unprotected arable land has been converted to agriculture or developed. The factors contributing to land cover change vary between the PAs, however distance to rivers and irrigated agriculture were consistently among the most influential drivers.

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