Preliminary Assessment of Carbon Storage & the Potential for Forestry Based Carbon Offset Projects in the Lower Tana River Forests:

the Tana Delta Irrigation Project and the Tana River National Primate Reserve

2005

Julia Glenday

Funded by the Critical Ecosystems Partnership Fund (CEPF)

Made possible by the support and input of ICIPE, TARDA, KWS, and the residents of Hewani, Wema, and Kulesa.

Acknowledgements

I would like to give great thanks to the two great, enthusiastic, fun, and knowledgeable field crew that I had the pleasure of working with in TDIP and TNRPR: Dara Garisse, Samuel Jilloh, William Kilimu (TARDA forestry officer), Mzee Dismus, Abio Gafo (Mchelelo Camp), and Morowa.

A big thanks goes to Dr. Ian Gordon and Ms. Mercy Ndigwa at ICIPE and Dr. John Watkin at CEPF for facilitating my work and taking care of innumerable logistics. A big thank you to everyone at TARDA, in Nairobi and Gamba, and at KWS, in Nairobi and Baomo, for permitting me to do this work and willingly assisting me with transport and lodging. Thanks also to the headmen of Hewani, Wema, Kulesa, and Sailoni, as well as innumerable village members for welcoming us, giving us directions, and allowing us to pass through their farms. Thanks also to Quentin Luke for suggestions and patience.

I also received great assistance from International Center for Research in Agroforestry (ICRAF) in Nairobi: to Elvis, Deacons, Andrew, George, Jane, Dominic, and the rest of the ICRAF soil labs and to Meshack Nyambenge, George, and Florence at the ICRAF GIS labs I owe you all a big vote of thanks. Thanks also to Byron and Minah at Regional Center for Mapping and Resource Development for helping me get a hold of satellite imagery.

Last, but not least a big thanks, to the Garisse family, the Jilloh family, the Lynam family, and of course my own family for giving help, laughs, meals, beds, and inspiration.

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Acronyms

CDM	Combined Development Mechanism (CDM), Kyoto Protocol Article 12, allows industrialized nations to receive certified emissions reductions credits (CERs) for funding greenhouse gas emission reduction projects in developing nations
CER	Certified Emission Reduction credit, issued to a nation, industry, or company that funds a CDM project indicating that a reduction/offset of GHG emissions occurred as a result of the project, the credit can be used towards achieving their GHG reduction quota or sold to another party
COP	Conference of the Parties, all nations that have ratified the Kyoto Protocol
dbh	diameter at breast height
FD	Kenya Forest Department
GHG	greenhouse gas, a gas which prevents heat from escaping the earth's atmosphere (CO_2, CH_4, N_2O, CFC, PFC, etc)
GIS	Geographical Information System, digitized maps containing spatially explicit data (data linked to spatial coordinates such as latitude and longitude)
GPS	Geographic Positioning System, system for determining geographic coordinates for point locations in the field
ICIPE	International Center for Insect Physiology and Ecology
KEFRI	Kenya Forest Research Institute
KIFCON	Kenya Indigenous Forest Conservation
KWS	Kenya Wildlife Service
NK	Nature Kenya
TARDA	Tana and Athi River Development Agency
TDIP	Tana Delta Irrigation Project
TRCC	Tana River County Council
TRNPR	Tana River National Primate Reserve
UNFCCC	United Nations Framework Convention on Climate Change

Conversions

*“**C**” denotes that a measurement refers to an amount of carbon*

1 t (metric tonne)	=		**1Mg**		=	**1,000 kg**
1 Gt	=	**1 Tg**	=	**1,000,000 Mg**	=	**1,000,000,000 kg**

Abstract

Emerging markets for carbon emission offsets may offer developing nations such as Kenya with added funding sources for reforestation and forest protection efforts. Rapidly rising atmospheric carbon dioxide levels have been linked to global warming and climate change. In an effort to mitigate this, there have been a number of internationally backed projects that offset carbon dioxide emissions by increasing storage of carbon in terrestrial pools. Projects that involve reforestation, afforestation, and deforestation prevention increase terrestrial carbon stocks, decreasing atmospheric CO_2 stock. Having ratified the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) in 2005, Kenya can now participate in the UN sponsored carbon market through the Clean Development Mechanism (CDM), as well as voluntary carbon markets.

Kenya is in need of reforestation and forest protection activities. Forest loss means loss of many valuable ecosystem services such as erosion protection, soil quality maintenance, microclimate stabilization, water filtration, fuelwood and other forest product provision, and species habitat. Much of Kenya's indigenous forest has been degraded or cleared over the past century and high rates of loss continue with 93,000 ha cut in the last decade (FAO, 2001). It has been estimated based on biophysical and climactic features, that Kenya has the potential to double its current aboveground biomass (Brown & Gaston, 1995), meaning that Kenya could at least double its storage of carbon in vegetation and soils.

The Lower Tana River Forests are scattered floodplain forest fragments growing in semi-arid conditions, supported by groundwater and flooding from Kenya's Tana River. These forests have existed in a cycle of senescence through desiccation in some areas and forest growth in others as the meandering river channel migrates. This has made these forests particularly vulnerable and forest cover has been lost due to changed flooding patterns from upstream dams and irrigation projects, intense flooding from 1997 El Nino events, forest clearing to meet local agricultural needs, and loss of new forest growth sites to riverine agriculture. These forests control erosion and water quality in the Tana, provide local communities with fuel, building materials, medicine, and foods, and provide one of the last habitat areas for endangered primates, the Red Colobus and Crested Mangabey. This study aims to assess the carbon storage value of these forests and the potential for carbon emission offset trading to help fund protection and rehabilitation of these forests in two sample sites: the Tana River National Primate Reserve (TRNPR) and the Tana Delta Irrigation Project (TDIP).

It was found that carbon densities in forest fragments in TRNPR and TDIP had values ranging from 160 to 260 Mg C/ha, intermediate values between those typically found in tropical dry and moist forests. 'Levee' forests which occur close to the river channel and are well fed by river groundwater and alluvial nutrient deposits had the highest carbon densities, while drier areas further from the river had significantly lower carbon densities and may have been undergoing a transition to woodland savanna or shrubland cover types. Total carbon stock for the TRNPR was estimated to be 1.4 ± 0.1 Tg C, but has decreased by at least 50,000 Mg C since 1992. Total carbon stock for the TDIP area was estimated to be 0.55 ± 0.05 Tg C, having decreased by roughly 29,000 Mg C since 1992. It is possible that carbon stocks lost since 1992, if not more, could be regained through reforestation, agroforestry, and forest protection strategies. Such projects could be tailored to both address local community resource and employment needs as well as produce tradable carbon credits. Proposed reforestation corridors for the TDIP area could increase the areas carbon stocks by 100,000 Mg C (0.1 Tg C), a project scale that has received carbon offset funding in the past and would qualify as a small-scale afforestation and reforestation project under the CDM

This report is meant to be relevant to both those experienced in issues of carbon storage and forestry and to those without background in the area. It is also written for both those familiar with Tana River forests and their history and to those unfamiliar with the area. Parts 1 and 2 contain introductory background information on these topics, but ***further reading and resource suggestions*** are listed in *Appendix G.*

Part one gives a brief description of the link between land cover change and global climate change, an introduction to international climate change mitigation policy such as the Kyoto Protocol's Combined Development Mechanism (CDM), and a summary key issues regarding Kenya's potential to participate in the carbon trading market through forestry and land-use/land-cover change projects.

Part two is an introduction to the biophysical conditions, historical and current managerial systems, and extractive forest uses in the Lower Tana River forests within the Tana Development Irrigation Project and the Tana River National Primate Reserve.

Part three describes the methodologies used to estimate the current carbon stock in the Lower Tana River forests based upon mean carbon densities (amount of carbon per unit area) in vegetation, litter, and soils for different forest types. This includes descriptions of tree biomass estimation, lab techniques, and remote sensing methods used to map cover types.

Part four provides the results of the carbon stock assessment, carbon densities of various forest cover types sampled, and an assessment of the impacts of cover change and anthropogenic disturbances on current carbon stocks.

Part five examines the potential to increase future carbon stocks and attract carbon based funding for this in the sampled areas in the TDIP and TARDA areas. One sample project scenario, the suggested reforestation of corridor areas delineated by the Critical Ecosystem Partnership Fund (CEPF), is given to illustrate the magnitude of added carbon stock such activities could accrue.

Part six makes recommendations for next steps towards project design and monitoring.

1. Introduction

Dry tropical forest is the most widely distributed habitat type in the tropics (Jaramillo et al, 2003), covering 42 % of all tropical vegetation (Murphy & Lugo, 1995). Dry forests typically have lower biomass densities than moist or wet forests, but store a significant amount of biomass carbon because they cover large areas. These ecosystems have become increasingly threatened by human utilization: a greater proportion of dry forests have been degraded or cleared than moist forests (Mooney et al 1995; Robertson et al., 199-; Jaramillo at al. 2003). **Riverine floodplain forests** in arid and semi-arid, human-inhabited areas are often cleared for agriculture because floodplains, with their nutrient deposits and higher water tables, make desirable farmland. **Land cover change** from tropical dry forest and savanna to agricultural and urban areas can result in *significant declines in total system carbon storage* due to: (Detwiler & Hall, 1988; Woomer, 1993).

- cutting and burning of aboveground biomass,
- loss of forest litter additions to the soil carbon pool,
- increased carbon release from soils through tillage

Releases of ecosystem carbon increase the **carbon dioxide (CO_2)** concentration in the atmosphere, promoting **global climate change** (Houghton, 1997).

The Lower Tana River Forests of Kenya have been identified as a biodiversity hotspot, supporting a unique plant taxonomy and a recorded 262 bird species and 57 mammal species including two highly endangered primates: the Red Colobus (*Colobus badius rufomitratus*) and the Crested Mangabey (*Cercocebus galeritus galeritus).* (Marsh, 1978; Medley, 1991) These riverine forest fragments have been recognized as an endangered ecosystem, suffering forest losses due to natural river course changes in combination with altered flooding regimes from upstream dams, land conversion for agriculture, and extractive forest use (Marsh, 1976, Gachugu, 1992).

Many ecosystem services of the Lower Tana River Forests, such as biodiversity preservation, erosion prevention, and forest resource supply, have been recognized and documented. These forests also provide an additional, global service by acting as a *carbon store*, and possibly a *carbon sink*, helping to reduce atmospheric CO_2 levels and mitigate global climate change. This study aims to quantify the current carbon stock in two areas of the Lower Tana River, the **Tana Delta Irrigation Project (TDIP)** and the **Tana River National Primate Reserve (TRNPR)**, and provide a preliminary assessment of the potential to increase carbon stocks in these areas and receive funding from emerging carbon-trading markets.

1.1 Carbon, the Kyoto Protocol, & the Combined Development Mechanism

a. Land cover change and the greenhouse effect

Concerns about human driven global warming and deforestation trends have driven scientific efforts to quantify the role of forests in the global carbon cycle and political efforts to make forest preservation more socio-economically attractive (Brown, 1997; Houghton, 1997; Watson et al., 2000). Since the Industrial Revolution, the concentration of CO_2 in the earth's atmosphere has steadily increased at a rate faster than any changes seen in the past hundred thousand years.

Human activities that produce atmospheric carbon include:

- fossil fuel (petroleum, coal) burning
- biomass (wood, vegetation) burning
- land cover changes (such as deforestation)

Because CO_2 gas traps heat in the earth's atmosphere like a blanket (the **greenhouse effect**), significant increases in atmospheric carbon are believed to impact the earth's climate. Several other gases, such as methane (CH_4) and nitrous oxide (N_2O), also prevent heat from leaving the atmosphere. These gases are also produced by human activities; however, due to high production levels, carbon dioxide is thought to have the greatest effect on the climate (Houghton, 1997). Climate models predict that the augmented concentration of these **greenhouse gases (GHGs)** will increase global average temperatures, leading to:

- changed local weather patterns
- increased numbers of storms, floods, and droughts
- global sea level rise

It is believed that **developing nations** of the subtropics will suffer much of the burden of these changes due to:

- increased aridity and loss of water resources
- loss of agricultural capacity and increased erosion
- loss of biodiversity and key ecosystems and/or reduced ecosystem function
- increased ranges of vector born diseases such as malaria

(Figueres, 2002)

While the majority of the recent increase in atmospheric carbon can be attributed to fossil fuel burning, it was estimated that land-use change, primarily the loss of forest cover, was responsible for 20-30% of the net increase over the last 20 years (Houghton, 1997). Plants remove carbon dioxide from the atmosphere (**carbon sequestration**) and use this carbon to build their body structures (their biomass) during photosynthesis. As a result, 50% of a plant's dry biomass is comprised of carbon. Forests, with their high density of woody vegetation, have much greater biomass than other vegetation cover types and hence store more carbon. Forests also maintain large stocks of carbon rich organic matter in their soils due to constant litter and deadwood production and relatively slow decomposition. Therefore, forests store large amounts of terrestrial carbon per unit area (high **carbon density**). In addition to storing carbon, forests may also act as **carbon 'sinks'** if the rate of carbon sequestration from plant growth exceeds the rate by which biomass carbon is returned to the atmosphere through natural decomposition and/or biomass burning.

As forests are converted to less carbon rich land cover types, such as agricultural fields or urban areas, much of the carbon stored in forest biomass and soil is released into the atmosphere and a potential carbon sink is lost. Globally, an estimated 13 million hectares of tropical forest was lost each year to deforestation (FAO, 1999) emitting between 5.6 and 8.6 Gt of carbon (Houghton at al., 1995). Preventing further deforestation and encouraging forest regeneration not only preserves biodiversity and other local ecosystem services, but may also mitigate global climate change by preventing the carbon stored in trees and soils from being released into the atmosphere. In addition, **reforestation** and **afforestation** (forest growth in an area not previously forested) activities could attract funds for sustainable development from emerging international carbon markets.

b. International treaties and carbon emissions offset trading

In an effort to mitigate global climate change, 154 nations, including Kenya, signed the **United Nations Framework Convention on Climate Change (UNFCCC)** in 1992. **Party nations** (nations which have *ratified*, accepted responsibility to implement, the convention) agreed to produce **national GHG emissions inventories**, assessing contributions from industrial and agricultural sectors, transportation, energy production, land cover change, and forest losses and growth within their borders. Knowledge of carbon storage trends is used to design climate models that forecast future climates and to identify key areas for emission reduction.

The UNFCCC acknowledges that industrialized nations hold the greatest responsibility for emitting greenhouse gases, while the developing world will suffer the brunt of the consequences. As a result, 41 listed **industrialized nations (Annex I)** were deemed responsible for reducing their collective GHG emissions. By 1997 the recommendations of the UNFCCC were consolidated into the **Kyoto Protocol** to provide a *'global action plan'* to implement GHG reduction activities (Figueres, 2002). The protocol entered into force in February 2005, binding industrialized parties to reduce their carbon emissions by the end of 2012 to levels below their estimated emissions in 1990.

Because atmospheric GHGs have global effects regardless of where they are released, in terms of the effect on the climate, it does not matter where emission reductions occur. In light of this, the Kyoto Protocol includes several '*flexibility mechanisms'* permitting industrialized nations to reduce global GHG emissions by investing in emission reduction activities in other countries, which is often more economical and efficient than taking emission reduction measures at home. One of these flexibility mechanisms, known as the **Combined Development Mechanism (CDM)**, Kyoto Protocol Article 12, party approved in 2000 and refined in 2001 (Marrakech Accords), allows industrialized nations to fund GHG emission reduction activities in developing nations in return for **certified emissions reduction credits (CERs)**. CERs help the industrialized nation achieve its emission reduction quota, while the funded projects promote less carbon intensive development in the developing nation and foster technology transfer. Such projects include the establishment of:

- forest regeneration activities
- timber plantations with sustainable harvesting rates
- energy efficiency improvements
- cleaner/renewable energy production and industrial manufacturing methods

provided that these activities produce measurable net GHG emissions reductions that would not have otherwise occurred without the CER investment (**additionality requirement**).

The CDM is administrated by an **executive board** consisting of elected representatives from each United Nations regional group, two industrialized nation representatives, two developing nation representatives, and a small island state representative and receives guidance from the **Conference of the Parties (COP)** that consists of all nations that have ratified the Kyoto Protocol. To participate in the CDM, nations must:

- ratify the Kyoto Protocol
- show that participation is voluntary,
- establish a **National CDM Authority** to facilitate, evaluate, and approve CDM projects

Industrialized nations must also establish an emissions reduction target, a national GHG emission inventory, and an emissions reduction accounting system with which to purchase reduction credits.

To prove **additionality**, that a project reduces net GHG emissions beyond what would occur without the project, a **carbon baseline** (*predicted carbon storage and emissions without the project*) must be established specifically for the project area in the developing nation. A project predicted to feasibly reduce atmospheric GHGs must then be approved by the host nation's National CDM Authority and evaluated by an independent party for approval by the executive board. Internal monitoring and subsequent independent review will be required for the executive board to issue CERs.

In addition to the market for CERs, there is also a **voluntary carbon trading market** for bodies interested in funding carbon emission reduction or carbon storing projects even if they are not mandated to do so. These bodies include aid agencies, American companies, trust funds, and various NGOs. The United States, which produces 20% of global anthropogenic GHG releases (Figueres, 2002), has not signed on to Kyoto; however, several American states have independently chosen enforce limits on emissions and American industries have funded forestry projects to counteract their emissions.

1.2 Forest carbon storage projects and Kenya's potential

Several forestry activities can offset emissions of CO_2 to the atmosphere. **Afforestation and reforestation** (**A/R**) sequester carbon from the atmosphere and store it in tree biomass. **Deforestation prevention** and **improved forest management practices** *(low impact use plans, sustainable harvest rates, enrichment planting, etc*) reduce carbon emissions that would have otherwise occurred had the forest been cleared or over exploited. During the first emissions reductions commitment period of the Kyoto Protocol (2008-2012), industrialized nations can receive CERs for funding A/R projects under the CDM. To avoid creating incentives to clear more forest, CDM CERs will only be issued for reforestation of areas **cleared pre-1990**. While deforestation prevention and improved forest management are not currently accredited in the CDM, possibilities for such projects to receive carbon funding in the voluntary carbon market and in future commitment periods of Kyoto after 2012.

National utilities, private companies, and international consortiums have begun to invest in forestry based carbon offset and storage projects (examples in **Table 1**) with over 150 bilateral projects having been developed by 2000 (Bass et al., 2000). For example, the Electricity Generating Board (SEP) of the Netherlands founded the Forest Absorbing Carbon Emissions (FACE) project to sequester the carbon it emitted from burning fossil fuels. FACE has funded forestry projects in the Czech Republic, Ecuador, and Uganda (WRI, 2000). As seen in *Table 1*, the cost of implementing these projects generally did not exceed the trading price for carbon credits.

Forest carbon offset projects could indeed assist Kenya by supplying financial assistance and incentives to slow the rapid disappearance of its forests. Model-based assessments of vegetation carbon storage in Africa suggest great potential to increase carbon stocks: much of the area with the biophysical capacity to support carbon rich tropical forests is currently degraded or deforested (Brown and Gaston, 1995; Zang and Justice, 2001). Based on analysis of rainfall, topography, temperature, and soil, Brown and Gaston (1995) suggest that Kenya could double its aboveground biomass carbon, and the deforestation of 93,000 ha of the Kenya's closed forest in the past decade (FAO, 2001) clearly suggests possibilities for forest protection and reforestation projects.

Table 1 Examples of existing carbon emissions offset forestry projects

Host country		Project location	Description	Approx. carbon storage (Tg C)	Approx. cost efficiency ($/Mg C)	International stakeholders and investors	Local partners	Source
Africa	Uganda	Bukuleba Reserve (residential agriculture & tropical forest)	pine and eucalyptus plantation on leased concessions	not given	not given	Tree Farms (company), Norwegian Afforestation Group	name not listed	World Rainforest Movement (2000)
	Uganda	Kibale National Park (tropical forest)	reforestation & preservation; indigenous species planted on degraded areas, protection	7.2	0.78	FACE (Dutch utility consortium), ClimateCare , Cooperative Bank	not listed (project includes local hire and management)	World Resource Institute (2002)
	Sudan & Benin	arid wooded savanna	tree protection, border planting	1 - 5	not given	UNDP, GEF, Near East Foundation	Range & Pasture Administration, Gov'ts of Sudan & Benin	FAO/ISRIC (2004)
	Tanzania	Kilombero District (residential agri with moist forest level rain)	pine and eucalyptus plantation on leased concessions	not given	3.50	Tree Farms (company), Tanzanian subsidiary	Sokoine University of Agriculture	FAO/ISRIC (2004)
	Tanzania, Uganda, India	various - rural residential agriculture	community agroforestry and on farm tree planting in farmer groups	3	not given	Tanzania/International Small Group Tree Planting (TIST), Clean Air Action (carbon credit broker - many investors)	2,600 groups in TZ, 66 groups in UG, 249 groups in India	TIST (2004)
Asia	Malaysia	(tropical forest)	reduced impact logging; local staff training, directional felling, harvesting plans, buffer zones	0.5	1.00	RIL Logging: New England Electric (NEES), Rainforest Alliance, COPEC	Innoprise Corp. (local timber concession holder)	World Resource Institute (2002)
	India	Rahtgaon & Handia Range Forests (dry deciduous forest)	forest protection, controlled extraction	0.5	15	USAID, Community Forestry International	Harda Forest Division	FAO/ISRIC (2004)
	India	Gudibanda Taluk (residential agriculture)	community planting of mango and jack fruit trees on farms	0.6	not given	Plan Vivo Trust Fund	Women for Sustainable Development (WSD)	FAO/ISRIC (2004)
	Malaysia	(tropical forest)	reduced impact logging	0.4	1.00	UtiliTree Carbon Co., Center of International Forestry Research (CIFOR), Rainforest Alliance	Forest Research Institute of Malaysia, Sabah Forestry Dept.	World Resource Institute (2002)
Latin America	Belize	Rio Bravo Reserve (tropical forest)	forest preservation; sustainable management, promote local alternative income projects to prevent forest clearing	5.0	0.52	UtiliTree Carbon Co., The Nature Conservancy, Wisconsin Electric Power Co., Cinergy Corp., Detroit Edison Co., PacifiCorp, etc (27 US utilities invested)	Programme for Belize, The Nature Conservancy	World Resource Institute (2002)

	Bolivia	Noel Kempf Reserve (tropical forest)	forest preservation; extend the area included in the protected reserve	6.8	1.25	American Electric Power, Inc (AEP), The Nature Conservancy	Fundación Amigos de la Naturaleza (FAN)	World Resource Institute (2002)
	Costa Rica	CARFIX Reserve (tropical forest)	forest preservation; sustainable management, promote local alternative income projects to prevent forest clearing, includes sustainable timber plantations	2.0	2.73	CARFIX, MERINEM, Wachovia Timberland Investment Management	FUNDECOR (local NGO)	World Resource Institute (2002)
	Costa Rica	(tropical forest)	forest preservation	1.0	0.90	ECOLAND: Tenaska Washington Partners, Trexler & Associates, National Fish & Wildlife Foundation	COMBOS, MIRENEM, Council of the OSA Conservation Area	World Resource Institute (2002)
	Ecuador	(tropical forest)	reforestation	9.6	0.59	FACE (Dutch utility consortium)	not given	World Resource Institute (2002)
	Guatemala	Maya Biosphere Reserve (tropical forest)	reforestation and preservation; protection, promote agroforestry to prevent forest clearing	36.8	0.38	CARE, AES (Allied Energy Services Corp.)	not given	World Resource Institute (2002)
	Guatemala	(tropical forest margins)	promote agroforestry, sustainable timber harvest, and increased cultivation efficiency to prevent forest clearing	not given	not given	Scandinavian aid agencies: DANIDA (Denmark), NORAD (Norway), SIDA (Sweden)	Tropical Agriculture Research and Education Center (CAITE) (regional science & education NGO)	World Resource Institute (2002)
	Paraguay	Mbaracayu Conservation Area (tropical forest)	forest preservation; protection, promote agroforestry to prevent forest clearing	14.6	0.27	AES, The Nature Conservancy, FMB Foundation, USAID	not given	World Resource Institute (2002)
	Mexico	Chiapas (agricultural, highlands and lowlands ecosystems)	Community agroforestry and on farm tree planting	15.0	12.00	Plan Vivo Trust Fund, Edinburgh Center for Carbon Management (ECCM)	AMBIO cooperative , Mexican gov't., individual farmers	FAO/ISRIC (2004)
	Peru, Ecuador, Bolivia	Amazonia (tropical forest)	forest preservation; tenure and sustainable management by indigenous groups	70.0	0.30	AES, OXFAM	not given	World Resource Institute (2002)

One potential barrier to Kenya's participation is the large amount of information needed to initiate a carbon project. General models identify lands that are **'technically suitable**' for carbon sequestration, areas that *could* support forest cover, but there is also need to determine which areas are **'actually available'** for such efforts (Iverson et al. 1993). Much of Kenya's area with biophysical capacity to support forest is used for smallholder agriculture or is surrounded by dense populations with high resource needs. Assessment of local socioeconomic, political, tenure, and cultural factors of areas helps ensure carbon storage activities can be achieved in a sustainable manner. A **carbon baseline** and **monitoring program** need to be established, requiring more detailed inventories than currently exist for many African forests and carbon inventories of any agricultural/ agroforestry systems involved. Fortunately, to encourage tree planting on small available areas or by landholder groups, the CDM board is working on *simplified project procedures* for **small-scale afforestation or reforestation (SSC-A/R) projects** storing 8,000 Mg C/yr or less.

There is concern that the carbon market will not direct funds to the relatively unmeasured African forests when competing with more intensively studied rainforests of the Neotropics (Goetze, 1999) and/or toward more easily measured monoculture plantations (World Rainforest Movement, 2000). There have been relatively few in depth carbon analyses of Sub-Saharan African indigenous forests even though they may account for one fifth of global net primary production (Cao et al., 2001). As well as the more extensive forest research, South and Central America also have a head start on setting up their National CDM Authorities and greater experience in determining what projects will and will not prove successful. Only a handful of projects have been attempted in Africa. Uganda and Tanzania have begun to participate with mixed success. The Kenyan Government has initiated a branch of **NEMA** (**National Environmental Management Agency**) to be the climate change and CDM authority, but has yet to finalize specific project approval guidelines or host a project.

Now that the Kyoto Protocol has come into force, economists predict rising prices for carbon credits (van ’t Veld & Plantinga, 2004), but, as Annex I nations can only use CDM credits to account for 5% of their carbon emissions at most, the competition for limited available project funding is already intense. For example, the $33.3 million BioCarbon Fund, a product of the World Bank to finance carbon storing land-cover change projects, opened in May 2004 and had already received 130 proposals and closed itself to new applications by December 2004. It is clear that information gathering and capacity building will be needed for Kenya to take full advantage of the CDM and the process needs to be timely.

a. Concerns in measurement and monitoring indigenous forests

Refining estimates of carbon storage in tropical African forests, while challenging, is crucial to understanding how maintaining or enhancing forest cover could be used to mitigate climate change and where Africa can best take advantage of the carbon market. Measurement methods for carbon storage in tropical forests are still evolving. Carbon storage estimates for African forests have been primarily based on extrapolation from a few forest surveys and inventory data from the United Nations Food and Agricultural Organization, the FAO (Brown and Gaston, 1995; Cao et al. 2001). Many existing forest inventories in Africa completed by government agencies have typically focused on commercially valuable trees which can underestimate carbon storage by ignoring high densities of small trees and/or noncommercial species (Cao et al. 2001).

Remote-sensing techniques can help determine the area of forest cover, but in **field surveys** are still needed to account for the range of biomass densities in closed canopy forest. Due to the high spatial variability typically found in tree species, tree sizes, and stem densities in tropical forest, it can be difficult to produce a reliable estimate of average carbon density for a forest without high sampling intensity: large numbers and/or sizes of sampled areas (Brown et al, 1995; Hall et al., 2001; Houghton et al., 2001; Keller et al., 2001; Chave et al., 2003). For a carbon-trading project, the frequency and intensity of forest monitoring impacts the amount of carbon sequestration that can be accounted for at the necessary precision for the sale of CERS.

Currently funded forest protection/regeneration projects show that suitable carbon stock estimates for natural forest can be achieved at non-prohibitive cost. Economic models developed to balance monitoring costs with carbon gains suggest **long-term average monitoring**, in which monitoring is performed every 5-10 years until a **stable long-term average** has been attained is often the most economical option in modeled forestry systems (Robertson et al., 2004). If carbon monitoring can be combined with other inventories funded by other means more frequent monitoring should be feasible.

b. Concerns in project design, management, & sustainability

Forestry carbon projects provide opportunities for improvements in:

- land cover management
- local employment
- environmental conditions/ ecosystem services
- biodiversity protection
- technology/information transfer

However, none of these are guaranteed benefits. For a forestry project to earn carbon credits, it must reduce or prevent carbon emissions that would have otherwise occurred. This doesn't ensure the project will be environmentally or socio-economically beneficial to the host nation or forest adjacent community.

Projects that do not address local resource needs and cultural concerns can prove difficult to maintain. Part of ensuring that a project actually increases net global carbon storage is accounting for project 'leakage.' **Leakage** refers to a loss of carbon storage outside of the project area as a result of project activities. For example, if a forest regeneration project prohibits adjacent communities from harvesting wood in the project area without addressing their wood needs, they may simply fell more trees or clear forest in another area. This will reduce the amount carbon stocks in this other area and reduce the overall ***net*** **carbon benefit** of the project. Local inhabitants under threat of resource alienation may resist project implementation. As a result, many successful projects have incorporated:

- alternative employment (not based on forest resource extraction)
- agroforestry and forest timber replacement
- agricultural and wood-use efficiency promotion.

Carbon trading profits can help fund these project components, which may subsequently produce their own financial returns. Sustainable projects that include poverty alleviation attract socially responsible corporate investors, who comprise much of the current carbon market, and generally have lower the risks of project failure (Figueres, 2002).

Two carbon-offset forestry projects in Uganda illustrate this. One project, which established pine and eucalyptus plantations on marginal agricultural lands, resulted in the eviction of 8,000 project area inhabitants without due compensation or firm evidence of substantial carbon benefits (Eraker, 2000 a; Eraker, 2000 b; World Rainforest Movement, 2000). After arson and destructive plantation felling by dissatisfied local residents, public criticism from NGOs, and an unfavorable carbon storage review, the investors withdrew and the project discontinued (Eraker, 2000 b). A project, with less contested tenure and more local involvement faired better. Degraded areas of Kibale National forest were replanted, storing 7.2 Tg C and employing local residents in project management, monitoring, and planting (Watson et al., 2000; World Resources Institute, 2002).

It is the job of a host nation's National CDM Authority to define its own **sustainability goals** in a transparent and participatory manner and use these to assess and approve carbon projects (Figueres, 2002). Guidelines for project design and management do exist to help project designers, investors, National CDM Authorities, and other stakeholder groups. The Climate, Community, & Biodiversity Alliance (CCBA) is producing a set of **project design standards** for issuing voluntary CCB certification to land-use based carbon offset projects. These include requirements for:

- measuring and documenting carbon baselines and project scenarios in a conservative manner acknowledging errors
- planning to prevent and monitor leakage
- proving the additionality of project activities and carbon benefits compared to the baseline
- upholding human rights
- working within established laws and land tenure agreements
- producing employment and other net benefits for local communities
- "appropriate and unbiased" community training
- ensuring community involvement and input in project design and management
- ensuring transparency of process and documentation
- producing a thorough project risk assessment
- promoting biodiversity preservation through project activities
- promoting water resource improvements through project activities
  (CCBA, 2004)

While national guidelines and methodologies for land-cover based carbon projects have not yet been decided, the Kenyan government has published its own general project approval criteria. These criteria closely resemble those proposed for CCBA certification, indicating that forestry based projects that pass through NEMA's approval process should not have trouble applying for CCB certification.

To receive Kenya government approval through NEMA, "*all CDM projects must satisfy the following requirements:*

- *Demonstrate firm and tangible contribution to sustainable development;*
- *Be supportive to and consistent with national development priorities and be pegged to poverty reduction;*
- *The technologies transferred must be locally appropriate and environmentally friendly especially, and demonstrate energy efficiency. Necessary precautions must be in place to avoid dumping of substandard technologies;*
- *Contribute to the enhancement of national institutional and human capacity building.*
- *Activities that generate maximum economic, social and environmental benefits should be accorded highest priority;*
- *Address community needs and priorities through effective public participation in project design, planning and implementation in order to ensure equitable distribution of sustainable development benefits.*
- *Contribute to global efforts to achieve stabilization of greenhouse gas concentrations in the atmosphere;*
- *The CDM financial inflows must be over and above the existing Official Development Assistance (ODA);*
- *Consistent with the objectives of the concurrent environmental conventions, including the Convention on Biological Diversity, the Ramsar Convention on Wetlands, and the Convention to Combat Desertification, Agenda 21, as well as with local and national environmental management laws;"*

(Government of Kenya, 2001)

2. Lower Tana River Forests background

2.1 Physical background and forest types

The **Tana River** is Kenya's longest river, starting from catchments in Mount Kenya and the Abedare Mountain range and flowing east and south before emptying into the Indian Ocean. The **lower Tana River** passes through semi-arid and arid plains, in which the river is solely fed from rain upstream in the highlands. Despite this region's dry conditions, the river's floodplain can support grasslands, bushlands, and **closed canopy riverine forest**. The floodplain forests occur in relatively small fragments which change size and location due to the limited area of suitable soils and water levels, the changing course of the river, flooding, and burning or clearance for cultivation (Marsh, 1976; Hughes 1990; Gachugu, 1992).

This study encompassed two different study sites containing fragments of this riverine forest in the Tana River District of Eastern Kenya. The **Tana River National Primate Reserve (TRNPR)** (1^{o} 11'-54' S and 40^{o} 5'-11' E) covers an area of 16,800 ha which is bisected by the Tana River. The **Tana Delta Irrigation Project (TDIP)** project area (2^{o} 9'-17' S and 40^{o} 9'-13' E) is on the east side of the river, south of TRNPR. The area represents the planned first phase of TDIP, encompassing 4,000 ha, of which 2,180 ha was earmarked for irrigated rice farming (Maitha et al, 1991). The two areas have similar climates and rainfall regimes, with mean monthly temperatures of 22-34ºC, roughly 500-600 mm of rain annually, and high evaporation causing rainfall deficits (2,250 mm annual free water evaporation, Maitha et al., 1991). They contain **floodplains** with Holocene alluvial sediments, from volcanic rock erosion in the highlands, deposited over tertiary marine deposits, and **dry plains areas** with unconsolidated Pliocene marine sediments (Marsh, 1976). Soil textures in the floodplains range from sands to clays depending on river channel migration and flooding.

A *meandering river*, it was estimated that bends in the Tana grow 3 m/yr on average causing frequent meander cut-offs forming oxbow lakes (Seal & MacDonald, 1991). The river has generally flooded twice a year corresponding to Kenya's rainy seasons (May-June and November-December), creating a floodplain of up to 6 km wide, with floods failing in roughly 2 out of 10 years. However, the five upstream hydroelectric dams and irrigation have altered this flooding pattern, significantly increasing flow in the dry season and decreasing the frequency of small magnitude flooding (Maingi and Marsh, 2002).

Past research suggests that riverine forest distribution and forest types in the area are greatly determined by the **length and frequency of flooding** and thus by its height above the river's bank full level (Hughes, 1990). Forest growth is also determined by **distance from the river** as the water table drops steeply with distance from the river course (Njue, 1992). **Closed canopy evergreen forest** is found growing on **well drained levees** near the river that are high enough to not receive frequent flooding and is generally found within 1km of the river (Hughes, 1990). These forests show characteristics of both dry and moist forests, having lower canopy heights and smaller maximum diameters than moist forests, more similar to dry forests, but a lower density of small trees than dry forest, more typical of wetter forest (Medley, 1990). While *frequent or intense* flooding has been seen to inhibit establishment of closed canopy forest and favor grasslands or bushlands, *low intensity* flooding has been found to promote germination and growth of canopy species (Hughes, 1990; Medley, 1990).

Table 2 Vegetation descriptions for Tana River National Primate Reserve

Vegetation type	Description	Characteristic species	Soil type	Years between floods	Source
Dry plains					
grassland / bushed grassland	Grass and scattered trees, generally found out of the floodplain	*Dobera glabra, Salvadora persica*			Decker, 1989
woodland / wooded bushland	Scattered trees at a higher density with shrubs and grasses, found out of the floodplain but also in low lying areas with impeded drainage	*Terminalia brevipes, Acacia species, Dobera glabra*			Decker, 1989
Evergreen floodplain					
active levee	Closed canopy forest generally 10-20m tall with 30m emergents, found near the river edge on raised levees	*Ficus sycomorus, Sorindeia madagascariensis, Sterculia appendiculata*	Sand	5 to 25	Hughes, 1990
inactive levee	Transition from active levee forest to lower lying forest types, found on levees adjacent to cut-off meanders and/or areas with over-bank floods depositing nutrient-rich clays	*as above with shrubs: Lecaniodiscus fraxinfolius, Thespania danis*	clay over sand		Hughes, 1990
clay evergreen	Closed canopy forest 20m tall with 30m *D.mespiliformis* emergents and increasing understory density with open canopy, found in low lying moist areas behind levees	*Garcinia livingstonei, Diospyros mespiliformis, Mimusops obustifolia*	heavy clay	2 to 3	Hughes, 1990
acacia forest	Open canopy forest/woodland 20-30 m tall which grades to dry bush at edge, found at the outer edges of the floodplain forests (1 km from river)	*Acacia robusta, Terminalia brevipes, Dobera glabra*	clay over sand at depth	1 to 12	Hughes, 1990
Pioneer vegetation					
point bar front pioneer	Low shrubby vegetation on low-lying sandy banks actively deposited inside meanders	*Populus ilicifolia, Pluchea discoridis*	sand, some silt	2 to 5	Hughes, 1990
point bar back forest	*Populus* forest on raised sandy banks behind point-bars	*Populus ilicifolia*	silt over sand, some clay	0.5	Hughes, 1990
oxbow pioneer	Shrubs and trees growing in oxbows formed by abandonned channel depressions from meander cutt-offs	*Terminalia brevipes (clay), Spirostachys venenifera (sand)*	sandy mouths, clay backs		Hughes, 1990
Other forest					
disturbed forest	Forest regenerating from fires, floods, and clearing, often having thick palm stands	*Hyphaene compressa, Phoenix reclinata*			Marsh, 1976
cultivated forest	Forest in or near cultivated or formerly cultivated areas with high densities of cultivated tree species	*Mangifera indica, Borassus aethiopum*			Marsh, 1976

Several distinguishable **forest types** in TRNPR have been described through relationships to the river, such as alluvial soil type, distance from channel, height above channel, and flooding regime (*Table 2*). While similar to forests in TRNRP, TDIP is further downstream and has a more complex river channel, more long-term flooding favoring grassland vegetation, and finer alluvial sediments (more clay areas, fewer sandy levees) than in TRNPR (Medley, 1992). The TDIP area has experienced great changes in river course since the late 1980’s (Luke, 2005) and thus several evergreen forest fragments were found up to 5 km from the river. These fragments maintain many typical species of riverine evergreen forests, but had higher frequencies of more dry-tolerant species, such as *Cynometra lukei*. TDIP's proximity to the coast also alters species composition compared to TRNPR. For example, *Barringtonia racemosa* and *Oxystigma msoo* have been commonly found in TDIP forests, but not in TRNRP (Medley, 1991).

In 1990, Hughes noted a **lack of tree regeneration** in TRNPR and predicted that with **dam altered river dynamics** - *fewer nutrient and sediment depositing surface-floods and less meander cutoffs* - that conditions for regeneration and establishment of new pioneer forests would be compromised. Short-rooted colonizer shrubs were expected to suffer from a *lower water table* and an decreased meander cut-offs, thereby reducing new growth of point bar and oxbow pioneer vegetation (Hughes, 1990). In levees no longer receiving floods, *Acacia* species were predicted to increase in dominance as they were seen to reproduce regardless of flooding. Indeed, in existing forests, Medley found *Ficus sycomorus* and *Acacia robusta* were the only canopy trees with significant self-replacement (Medley, 1990). Irrigation dykes around the TDIP area were predicted to further prevent flooding in some forest areas, again effecting regeneration (Maitha, 1991).

Being a managed reserve, the TRNPR area was presumed to have more intact riverine forest than surrounding areas, and forest fragments in TDIP were considered the most intact riverine forest south of TRNPR (Medley, 1990). However, forest structure in TRNPR was described as *'disturbed'* with low average height, stem density, and coverage and dominance by a few species (Medley, 1992). Similarly, the TDIP forests were deemed to have low tree species diversity (Medley, 1989) and a recent environmental impact survey of the TDIP forest fragments concluded that forest quality had deteriorated significantly since 1988 (Luke, 2005).

2.2 Management

It is thought that the lower stretches of the Tana River were settled in the mid-17th century by the Bantu group now called the **Pokomo** (Decker, 1989). The Pokomo have generally been riverine agriculturalists, fishing and farming communally allocated plots in the floodplain, with Orma and Wardei pastoralist groups grazing the plains seasonally. In 1926, the British Colonial government divided land into '**Native reserves**,' where local people could reside, and '**Crown land**,' with limited access for local populations. The division was largely ignored in the Tana District, but after independence (1967) Native Reserves became '**trustland**' to be managed by the **Tana River County Council** (Gachugu, 1992)**.** On an official level, Pokomo group governance by clan elders was replaced with government appointed chiefs**,** one for each Location of several villages (Gachugu, 1992). Chiefs were given authority to issues licenses for use of forest resources and land. The TRNPR areas and TDIP areas later came under different management regimes.

The **Tana River National Primate Reserve (TRNPR)** area was gazetted in 1976 to protect the two endangered primate species residing in Tana's riverine forests: the red colobus (*Colobus badius rufomitratus*) and the creseted mangabey (*Cercocebus galeritus galeritus).* National Reserve status meant that the area came under the management of the Game Department, replaced by **Kenya Wildlife Service (KWS)** in 1990. Animal poaching in the area was prohibited and efforts were made to prevent further forest clearance. Those with farmland within the gazetted area have been permitted to access this land.

Starting in 1996, the **Global Environmental Facility (GEF)** of the World Bank provided funding for development and implementation of a management plan for TRNPR in cooperation with KWS. The project was to include improved sustainable management of forest use, increased monitoring activities, community involvement, ecotourism promotion, reforestation, and voluntary relocation of reserve residents. For the reforestation project, a nursery was initiated to research growing conditions of indigenous species and 20 ha were to be planted each year for at least 3 years in open forest patches (KWS, 2001) However, due to a number of setbacks and tense relations between project proponents and local residents, particularly regarding relocation issues, World Bank funding was withdrawn in 2001. While KWS retained community-relations personnel, reforestation and habitat monitoring programs had been effectively discontinued at the time of this study. The initial KWS-GEF nursery had been established on hardpan soils. The vast majority of planted seedlings failed and the area was abandoned.

The **Tana Delta Irrigation Project (TDIP)**, a rice-growing irrigation scheme, was initiated by the **Tana and Athi River Development Agency (TARDA)** with funding from the Japanese government. The project was established on trustlands on the lower Tana River containing five villages: Hewani, Wema, Kulesa, Bvumbwe, and Sailoni. Land was granted to TARDA by the County Council in 1970s and a **flood dyke** was constructed around 4,000 ha project area in 1989. Further dykes were proposed, however after the 1997 El Nino damaged the first set and without continued funding, no more were built. Of the built polder, 2,180 ha were intended for rice cultivation with 1,930 ha to be farmed in a government managed estate system and 290 ha to belong to local farmers.

The TDIP forest patches, as part of the trustland, are technically government land and to be managed by TARDA. However, while continual forest monitoring, forest clearance prevention, and restricting large tree removal were suggested TDIP project activities (Maitha, 1991), at the time of study no monitoring program was in place. The TDIP project was also to include **timber plantations** and **reforestation** efforts. While some woodlots of *Senna siamea*, *Eucalyptus* species, *Azadirachta indica*, and *Pithecellobium dulce* were planted in the early 1990s, the plantations were badly damaged in 1997 El Nino (Nippon Koei, 1998; Kilimu personal communication) and little effort has been made to rejuvenate them, make the wood available to communities, or extend planting to the encompass the original planned area. TDIP has retained a small-scale tree nursery that provides tree seedlings to local residents.

At the time of study, forests in both areas were receiving renewed attention. In TRNPR, communities that had volunteered for funded relocation in the GEF project were demanding to either be moved or to clear forest. In response KWS was re-evaluating relocation efforts and funding. In the TDIP area, JBIC was considering funds for improving the damaged irrigation program with added attention to forest rehabilitation. The Kenyan government was conducting preliminary research for sugar cane production in the area as well as expanding livestock exports to aid Tana pastoralist groups.

2.3 Forest use, land use, & land cover change

Most of the area both in TRNPR and the TDIP locations is dry grassland and woodland with relatively small, forested patches along the river. Forest cover has changed due to river migration and flooding, but increasing human impacts such as clearance for agriculture and dam and dyke construction have significantly contributed to **forest loss and loss of forest carbon stocks**. Communities living in and around TRNPR and TDIP rely on the remaining forest for a variety of extractive resources such as fuelwood, building poles, canoe wood, thatching material, palm wine, and medicinal plants. While subsistence level use hasn't resulted in forest clearance, increasing populations are putting pressure on small forest areas with noticeable effects on **forest structure**, likely effecting carbon storage.

People have been farming and grazing the lower Tana River floodplain for almost 400 years. Pokomo farmers generally had narrow properties bordering the river and sometimes, additional plots on backswamps and oxbow lakes (Gachugu, 1992). Unfortunately, these desired, fertile, well-drained areas, are also the primary areas for forest growth and regeneration in the floodplain. In addition, some pastoralist groups that historically moved closer to the river for grazing in dry periods, have settled in villages bordering TDIP and TRNPR. In 1991, the TDIP area contained the villages of Kulesa, Bvumbwe, Wema, Hewani, with Gamba and Sailoni on its southern and northern borders. In 1990 the population of this area was considered to be 4,900 with 576 households (Maitha et al., 1991). It was estimated that 10,000 domiciled users cultivate in or adjacent to TRNPR with a similar number of seasonal grazers (Seal et al., 1991). Growing populations in the region (3.4% growth in 1991) have led to competition and conflict for land between agriculturalists, pastoralists, forest growth and wildlife.

Table 3 Estimates of forest cover within the Tana River National Primate Reserve (TRNPR), 1960-2000

Year	**Forest cover estimate** (ha)	**Change** (%)	**Rate of change** (ha/yr)	***Source***
1960	1,740			Gachugu, 1992
1975	1,390	-20%	-23	Gachugu, 1992
1991	1,990	43%	38	Gachugu, 1992
(1991	*1,750*			*Kinniard, 1991)*
(1993	*1,100*			*Kahumbu, 1993)*
1992	640			Tabor et al., 2003
2000	570	-11%	-9	Tabor et al., 2003

Estimates of forested area within TRNPR over past decades have been made using aerial photographs, satellite imagery, and field surveys in previous studies. These studies haven't always reported similar estimates, but do generally indicate *increasing* **forest fragmentation** and *fluctuating rates* of **forest loss** *(Table 3)***:**

- **1969-1975:** *loss* of 20% of forested area (340 ha) within TRNPR, and 19% loss (390 ha) including the surrounding areas assessed (Gachungu, 1992)
- **1975-1991:** *gain* of 43% of forested area (600 ha) within TRNPR, and 48% gain (780 ha) including the surrounding areas assessed (Gachungu, 1992).
- **1989-1996:** mean forest extent from the river decreased by 200m and mean forest fragment size decreased by 31% (Maingi, 1998)
- **1992-2000:** *loss* of 10% of forested area (63 ha) within TRNPR, and 12% loss (390 ha) including the surrounding areas assessed, (Tabor et al, 2004)
- **1994-2000:** estimated loss of 20% of forested area in the TRNPR area (Mbora, 2000; Wieczkowski and Mbora 1999-2000).

Records of the change in forest area in **TDIP** have been less quantitative, however clearing of TDIP forests for agricultural plots (in fragments 59, 61, 62) was reported in 2000 (Muoria et al., 2003) and was seen in 2005 in both TDIP and TRNPR during this study. A primate survey in 2005 suggested that 34% of the closed forest had been cleared since 1994 (Cunneyworth, in Luke, Hatfield, Cunneyworth, 2005).

While population growth and low yields have driven **expansion of agricultural areas**, these are not the only factors driving forest loss in the Tana floodplains. Aerial photo analyses in TRNPR indicated that, of the forest loss from 1960 to 1990, 51% was caused by declines in the *hydraulic regimes*, 3% from *bank erosion*, and 46% from *forest clearance* (Seal et al, 2001). The ratio of forest to farm decreased from 50% to 35% between 1960 and 1975, but increased again to 61% by 1991 (Seal et al. 2001). Gachungu estimated that there was both an increase in forest cover and a decrease in farmland between 1975 and 1991 both inside and around TRNPR, despite the near doubling in population between 1969 and 1991 (Gachungu, 1992). It is possible that forest clearance and agricultural expansion was slowed in that time period due to unrest and violence with 'shifta' (bandit) groups in the area.

Dams upstream of TRNPR and TDIP have also influenced forest cover by changing ***hydraulic regimes***. Five dams built in the late 1960's to 80's, have significantly *reduced* the frequency of small and medium floods (2-5 year floods) and *increased* minimum river flow (Maingi and Marsh, 2002). Less flooding has likely lowered groundwater levels, and may explain forest senescence at outer edges. Increased minimum flows could increase *meander migration*, but a lack of flooding could decrease *bank breakthroughs* that produce oxbows. Analyses of river migration between 1969-1975 indicated that every river loop in TRNPR had migrated, causing forest dieback in dried out areas (Seal & MacDonald, 1991). Dams reduce *downstream sediment loads* and *low-intensity floods*, hindering riverine forest regeneration that would make up for losses. Agricultural expansion into bank areas opened by channel migration also breaks riverine forests' senescing/regenerating cycle by taking up areas where new forest could grown to replace forests drying out elsewhere.

Construction of **irrigation dykes** in **TDIP** has also affected forest cover. Dyke building required clearance of some forested area and further fragmented several forest patches (fragments 48, 56, 57, 59, 65, 67, & 69)(Suleman et al., 2001). Changed hydraulic regimes in and around the dyke will have dried some areas and maintained groundwater in others. In addition, irrigation schemes on the Tana have increased population densities, increasing the demand for extracted forest products.

In addition to loss of forest cover, **extractive use** of subsistence forest products may have decreased forest biomass and carbon stock in the remaining forest patches. It was observed **building poles** and tree trunks for canoe carving came from the *forest*, but most households got **fuelwood** from *woodland areas* rather than intact forest (Medley, 1990). Fuelwood demand for the 6 TDIP villages was estimated at 24.6 Mg/week (Nippon Koei) and harvesting was seen as far as 10 km from home in TDIP perhaps indicating scarcity (Maitha et al. 2001). Other population centers in the Tana River delta had already seen fuelwood scarcity in the 1980's: around the Bura Irrigation Scheme great increases in fuelwood demand caused marked encroachment of harvesting into *forest edges* (Hughes, 1988; Maitha et al, 1991). Recent reports of extractive use within the TDIP *forests* included: tree felling, charcoal pits, forest grazing, palm harvesting, harvesting poles and thatch, and burning of forest edges to increase grazing land (Muoria et al., 2003; Luke, 2005). Pole harvesting was found to be the most commonly observed anthropogenic disturbance (Muoria et al., 2003)

Signs indicate that forest loss trends may continue in future without intervention. Forest clearance and increased extraction will likely continue without a change in incentives for local residents. Reforestation, a planned part of both TDIP and TRNPR projects, has not been successfully initiated and should the TARDA sugar cane trials prove successful, land for this cash crop will also be in high demand. **Climactic changes**, upstream dams, and continued **watershed deforestation** will also contribute to forest loss. Dams and dykes *do not* prevent **high intensity floods** such as that of **El Nino 1997**, which caused dieback of many mature trees due to long term lack of oxygen in waterlogged soils. Global climate change is predicted to increase droughts, high intensity floods, and El Nino events. These will be compounded by the high levels of deforestation in Mount Kenya and the Abedares, the source of the Tana River. Lack of watershed forest both increases aridity and increases flood intensity by increasing surface runoff rather than soil percolation in rain events.

3. Methodology

3.1 Inventory plots

Carbon density in riverine forests in TRNPR and TDIP was estimated with data from 148 circular, 20m-radius (0.126 ha) inventory plots sampled in February-March 2005 (62 plots in TDIP and 80 plots in TRNPR). In each plot, six major **carbon storage pools** were assessed (Brown, 1997; MacDicken 1997):

- live tree aboveground biomass,
- tree belowground biomass,
- coarse deadwood (≥10 cm diameter),
- litter,
- herbaceous vegetation,
- soil

Plots were randomly placed both within forest patches and on patch edges with the number of plots sampled in each fragment roughly proportional to the fragment size. Forest fragments have been assigned numbers and names in previous surveys and these will be used in this study (*Appendix A*). Plot positions and observed timber or fuelwood cutting, were recorded using a GPS unit and **geo-referenced** to land-cover maps. An additional 8 sample plots were measured in the small planted exotic woodlots in the TDIP area.

a. Vegetative biomass carbon

Carbon densities (Mg C /ha) in each plot were calculated from **biomass densities,** assuming 50% of vegetative biomass is carbon (MacDicken 1997). To quantify aboveground biomass, tree and liana diameters were recorded at 1.3 m from the ground (**diameter at breast height or dbh**), in ninety-seven inventory plots using a nested sampling design:

- Within a 4 m radius of the plot center, all trees with dbh ≥5cm were measured
- Within a 14 m radius of the plot center, all trees with dbh ≥20cm were measured
- Within a 20 m radius of the plot center, all trees with dbh ≥40cm were measured

The species of each measured tree was recorded in local or botanical name (*Appendix B*) and an **importance value** of each species observed in a forest type was calculated as described by Brower et al. (1998):

$$\textbf{\textit{Importance value}}_x = \frac{\textit{relative density}_x + \textit{relative frequency}_x + \textit{relative coverage}_x}{3}$$

- ***relative density**$_x$ = number of trees of species x / total number of trees observed*
- ***relative frequency**$_x$ = frequency species x amongst sample plots / sum of frequencies of all species*
- ***relative coverage**$_x$ = % sampled area covered by species x basal area / sum of all % coverages*

Aboveground biomass (AGB) of each tree was calculated based on diameter using a generalized tropical *moist forest* equation for species that typically grow with access to groundwater and a generalized *dry forest* equation for species typically found in cover types established further from the river channel (*Appendix C*). Palm biomass was calculated based on height and *Eucalyptus spp*. biomass was calculated using a species-specific equation.

Moist forest AGB (kg) = $e^{\{-2.134+2.53*\ln(\textbf{dbh}\text{ cm})\}}$ *(Brown, 1997)*
Dry forest AGB (kg) = $e^{\{-1.996+2.32*\ln(\textbf{dbh}\text{ cm})\}}$ *(Brown, 1997)*
Palm biomass (kg) = 4.5 + 7.7 * **stem height** (m) *(Brown, 1997)*

Belowground tree biomass (BGB) was calculated for each tree using a regression equation relating aboveground biomass density (AGB) to **root biomass density (RBD)** derived for tropical trees:

$$\textbf{RBD}\ (\text{Mg/ha}) = e^{\{-1.0587+0.8836*\ln(\textbf{AGB}\ \text{Mg/ha})\}} \qquad \textit{(Cairns et al.,1997)}$$

Coarse deadwood biomass was estimated in each plot using the transect method described by Harmon & Sexton, 1996. Diameters were recorded for all downed trees and branches with diameters≥10 cm crossing two perpendicular 40m transects (the north-south and east-west diameters of the inventory plot). Each piece measured was given a decomposition ranking: rotten, intermediate, or sound. The biomass density of deadwood was calculated using tropical dry forest deadwood densities for the three decomposition classes reported by Jaramillo, VJ et al., 2003. **Standing dead trees** were measured with the live trees, but given decomposition rankings with which to scale down biomass.

Clip plots were used to measure **understory vegetation** and **litter** (MacDicken, 1997). Four 0.5 x 0.5 m subplots were established 10 m from the plot center in each cardinal direction. All understory vegetation in the four subplots was cut and placed in a weigh bag. The wet weight was recorded, the sample was well mixed, and an 80-200g sub-sample was weighed, air dried for at least 3 weeks, and reweighed. The wet to dry weight ratio of the sub-sample was used to estimate total dry weight for herbaceous vegetation. This same procedure was followed for litter collected in each clip plot after herbaceous vegetation removal.

b. Soil carbon

Soil was sampled in half of all inventory plots as soil carbon content was predicted to be low. Three soil samples were collected in an inventory plot from the bare ground revealed after clearing vegetation and litter from the clip-plots. Soil cores were taken with a tube corer to a depth of 30 cm and separated into 10 cm depth intervals. Samples were air-dried, passed through a 2mm sieve, and subsequently weighed. Bulk density was calculated using the measured weight of each dried, sieved sample divided by the core volume.

Sample carbon concentrations were predicted using the spectral library approach described by Shepherd and Walsh, 2002. All samples were analyzed by diffuse reflectance spectroscopy, using a FieldSpec FR spectroradiometer (Analytical Spectral Devices Inc., Boulder, Colorado) at wavelengths from 0.35 to 2.5 μm with a spectral sampling interval of 1 nm using the optical setup described in Shepherd et al., 2003. Soil carbon was measured on a random selection of 15% of the samples by acid oxidation. Measured concentrations for this subset were used to calibrated the reflectance spectra using partial least squares regression with Unscrambler 7.5 © software (CAMO Inc., Corvallis, OR., USA). The regression models were used to predict C concentrations for all samples (*Appendix D*). The average carbon concentration at each depth was found for each sampled strata and multiplied by the bulk density to estimate soil carbon density (Mg C/ ha).

c. Plot classification

Plots were classified on the basis of species composition (from importance values) and soil type into the following discernable **forest classes**:

- **levee evergreen forest**: dominated by *Ficus sycomorus, Sorindeia madagascariensis, Sterculia appendiculata,* and/or *Synsepalum msolo* found on sandy soils
- **clay evergreen forest:** dominated by *Garcinia livingstonei, Diospyros mespiliformis,* and/or *Mimusops obustifolia* found on clay soils

- **clay/levee evergreen forest:** similar species to levee forest but with significant contributions from clay evergreen species and often found on clay soils. Predominantly found in TDIP, may be the 'levee' forest that develops lower in the river basin where finer sediments are deposited.
- **transitional vegetation/woodland:** dominated by *Acacia* species, shrub species *(Terminalia brevipes, Dobera glabra Lecaniodiscus fraxinfolius, Thespania danis)* or palm species *(Hyphaene compressa, Phoenix reclinata, Borassus aethiopum).* These areas could represent stable woodland, senescent forest from loss of groundwater access, or regenerating damaged forest.

Plots were also given an observed canopy closure ranking (open, medium, closed, or low thicket). Mean carbon densities were estimated for each forest class.

d. Stump measurements: recent disturbance & historical forest structure

In each inventory plot, stump species and diameters were measured using the same nested subplot design described above (*section 3.1.a*). Stumps appearing to have been cut within the past six months were classified as 'fresh' by visual assessments (wet wood, lack of decay or insect damage on cut surface, green leaves on cut branches, etc). For commonly felled species, both **diameters at ground level (dgl)** and dbh measurements were taken on living trees. The dgl/dbh ratio was applied to stump dgls to estimate former dbh and calculate former biomass. Estimated biomass removal was used to assess disturbance levels.

3.2 Landscape scale assessment

a. Mapping forest cover types

The area covered by forest, woodland, and open cover types was determined using cover maps derived from post-hoc spectral analysis of Landsat satellite images (*scene*: 166/61, *images*: 6/1992 from Landsat TM, 2/2000,12/2003 from L7 ETM). Images were selected based on lack of cloud cover. Spectral analyses were performed using the "maximum likelihood function" in ENVI 4.1 (copyright Research Systems, Inc., USA) remote sensing software. Locations with vegetative cover that clearly fit land cover type descriptions were GPSed in the field and used as 'training classes' in the satellite images. The separability of the average spectra for the training class areas for the cover types was estimated using Jeffries-Matusita separability index (calculated by ENVI 41.) and classes with values lower than 1.95 were either lumped or new training area pixels chosen to achieve this value.

Image pixels were assigned to land cover classes based upon their spectral similarity to the average spectra of training class areas. Small areas that could not be assigned to a ground cover class due to cloud interference in the 2003 image were assigned based on their classification in the 2000 image. Classification accuracy was determined using field classification of GPSed points not included in the training set. The resulting map was compared with previous maps and to estimate forest cover and identify land cover changes.

b. Scaling up to forest level: aggregation & extrapolation

Individual **plot carbon density** was calculated as the sum of carbon densities found in all six measured carbon pools. The **average carbon density for a cover type** was calculated by taking the mean of all plot carbon densities in that type. Total carbon stock was estimated by multiplying average carbon density estimates by the estimated area covered by each type.

3.3 Statistics & Uncertainty

One-way ANOVA was used to detect statistically significant differences between carbon density averages amongst forest types. Pair-wise comparisons between classes were made using standard student's t-tests, except in cases where data had a significantly non-normal in distribution. In these cases Tukey's HSD test was used for pair-wise comparisons.

Both *measurement uncertainties* in measuring plot radius and tree diameter and the *applicability of the regression equation* used to the growth forms of the forest sampled contribute to the uncertainty in carbon density estimates. However, it has been repeatedly found that measurement uncertainties contribute an insignificant amount to overall **uncertainty in the mean** compared to uncertainty introduced by natural variations of carbon density between individual plots of one forest type (Chave et al. 2003, Keller et al 2001, Brown et al. 1995). Without destructive tree sampling, non-viable in a protected reserve, the applicability of the generalized dry forest equation used cannot be assessed. For these reasons only *sampling error*, rather than sampling, measurement, and equation errors, was included in the **95% confidence interval (95% CI)** estimates presented for all mean values. A **sensitivity analysis** was used to assess the influence of various definitions of forest cover types and various estimates of forest type areas on the total carbon stock estimate.

4. Results

4.1 Forest structure

Plots were classified into forest types based upon dominant species (*section 3.1.c*), therefore forest type species compositions conformed well definitions and previous studies (*see Table 2*) Within each **forest type**, species composition showed few marked variations between TDIP and TRNPR (*Table 4*).

In **levee** and **clay/levee forest**, *Barringtonia racemosa* was dominant in TDIP, but not seen in TRNPR, while *Synsepalum msolo* was dominant in TRNPR, but not TDIP. *Ficus sycomorus* was among the top four dominating species in all cases. *F.sycomorus* was one of the few species seen to be successfully regenerating in previous studies (Medley, 1991). The greater dominance of palm species (*Phoenix reclinata*, *Hyphaene compressa*, and *Borassus aethiopicum*), being post disturbance pioneers and savanna edge species (Medley 1992), and mango trees (*Mangifera indica*), a cultivated exotic species, in TDIP levee forests indicates high levels of disturbance and human influence compared to TRNPR. **Clay evergreen forest** and **transitional vegetation/woodland areas** had very similar species compositions in both locations, although palms (*P. reclinata*) were again more common in TDIP areas..

Tree size distribution patterns varied between forest types and locations (*Figure 1*). In general, **TDIP** areas sampled had *lower* stem densities in the smallest size class (5-10 cm) than **TRNPR** areas across forest types. Low small tree density could be due to physical properties of the location or anthropogenic influences such as fuel and polewood harvest, grazing, and trampling of seedlings from use. **Transitional forest/woodlands** had the highest density of small trees and the lowest density of larger trees. **Clay evergreen areas** followed a similar size distribution curve but with more larger trees and fewer in the smallest size classes. **Levee areas** had the highest concentration of very large trees.

Table 4 Importance values for the top 10 species dominating sampled areas of the different forest types in TDIP and TRNPR, 2005

Importance values calculated from relative frequency, relative stem density, and relative basal area as described in methods 3.1.a

** In TDIP most levee plots were clay/levee, only 3 were sandy levee, while in TRNPR most levee plots were sandy while only 2 were clay/levee.*

Levee forest (sand)

All		TDIP*		TRNPR	
Species	**importance value**	**Species**	**importance value**	**Species**	**importance value**
Polysphaeria multiflora	24.5%	*Sorindeia madagascariensis*	25.0%	*Polysphaeria multiflora*	25.5%
Sorindeia madagascariensis	10.9%	*Ficus sycomorus*	21.8%	*Sorindeia madagascariensis*	10.1%
Ficus sycomorus	9.1%	*Barringtonia racemosa*	14.5%	*Ficus sycomorus*	7.7%
Synsepalum msolo	6.4%	*Mimusops obtusifolia*	11.1%	*Synsepalum msolo*	7.1%
Cordia sinensis	4.3%	*Polysphaeria multiflora*	7.2%	*Cordia sinensis*	4.5%
Alangium salviifoilum	3.8%	*Oxystigma msoo*	6.4%	*Alangium salviifoilum*	4.2%
Drypetes nataliensis	3.2%	*Blighia unijugata*	5.0%	*Spirostachys venenifera*	3.5%
Spirostachys venenifera	3.2%	*Kigelia africana*	3.7%	*Diospyros mespiliformis*	3.5%
Diospyros mespiliformis	3.1%	*Garcinia livingstonei*	2.7%	*Drypetes nataliensis*	3.4%
Hyphaene compressa	3.0%	*Phoenix reclinata*	2.7%	*Hyphaene compressa*	3.3%

Clay/levee forest

All		TDIP		TRNPR*	
Species	**importance value**	**Species**	**importance value**	**Species**	**importance value**
Ficus sycomorus	12.9%	*Ficus sycomorus*	13.2%	*Diospyros mespiliformis*	22.7%
Polysphaeria multiflora	12.1%	*Polysphaeria multiflora*	12.9%	*Diospyros kabuyeana*	12.3%
Sorindeia madagascariensis	10.8%	*Sorindeia madagascariensis*	11.4%	*Phoenix reclinata*	12.2%
Phoenix reclinata	8.1%	*Barringtonia racemosa*	8.7%	*Ficus sycomorus*	11.4%
Barringtonia racemosa	8.0%	*Oxystigma msoo*	8.4%	*Cola minor*	8.7%
Oxystigma msoo	7.6%	*Phoenix reclinata*	7.9%	*Antidesma venosum*	6.7%
Mangifera indica	7.0%	*Mangifera indica*	7.8%	*Mimusops obtusifolia*	6.5%
Mimusops obtusifolia	5.0%	*Borassus aethiopum*	5.5%	*Garcinia livingstonei*	5.9%
Borassus aethiopum	4.9%	*Mimusops obtusifolia*	4.9%	*Albizia glaberrima*	5.9%
Antidesma venosum	3.3%	*Antidesma venosum*	3.0%	*Sorindeia madagascariensis*	3.9%

Clay evergreen

All: Species	All: importance value	TDIP: Species	TDIP: importance value	TRNPR: Species	TRNPR: importance value
Garcinia livingstonei	16.2%	*Cynometra lukei*	14.7%	*Garcinia livingstonei*	18.2%
Cynometra lukei	14.6%	*Garcinia livingstonei*	14.6%	*Mimusops obtusifolia*	16.3%
Mimusops obtusifolia	12.9%	*Spirostachys venenifera*	11.3%	*Cynometra lukei*	14.6%
Spirostachys venenifera	8.4%	*Mimusops obtusifolia*	10.0%	*Rinorea elliptica*	11.4%
Rinorea elliptica	8.3%	*Polysphaeria multiflora*	8.2%	*Polysphaeria multiflora*	6.3%
Polysphaeria multiflora	7.3%	*Sorindeia madagascariensis*	8.2%	*Spirostachys venenifera*	4.9%
Sorindeia madagascariensis	4.7%	*Rinorea elliptica*	5.8%	*Lamprothamnus zanguebaricus*	4.7%
Phoenix reclinata	2.8%	*Phoenix reclinata*	5.2%	*Cola minor*	4.2%
Lamprothamnus zanguebaricus	2.3%	*Lecaniodiscus fraxinifolius*	2.4%	*Acacia robusta*	3.5%
Cola minor	1.9%	*Antidesma venosum*	2.4%	*Diospyros mespiliformis*	2.8%

Transition / woodland

All: Species	All: importance value	TDIP: Species	TDIP: importance value	TRNPR: Species	TRNPR: importance value
Lecaniodiscus fraxinifolius	11.5%	*Lecaniodiscus fraxinifolius*	15.6%	*Acacia robusta*	13.2%
Thespesia danis	11.1%	*Thespesia danis*	15.5%	*Lecaniodiscus fraxinifolius*	9.5%
Acacia robusta	11.1%	*Acacia robusta*	6.3%	*Thespesia danis*	8.9%
Terminalia brevipes	5.6%	*Terminalia brevipes*	5.2%	*Polysphaeria multiflora*	7.5%
Polysphaeria multiflora	5.4%	*Cynometra lukei*	4.9%	*Terminalia brevipes*	5.7%
Garcinia livingstonei	4.6%	*Phoenix reclinata*	4.7%	*Ficus sycomorus*	5.4%
Ficus sycomorus	4.3%	*Garcinia livingstonei*	4.7%	*Hunteria zeylanica*	4.7%
Mimusops obtusifolia	4.3%	*Mimusops obtusifolia*	4.5%	*Garcinia livingstonei*	4.5%
Hunteria zeylanica	3.8%	*Antidesma venosum*	4.3%	*Mimusops obtusifolia*	4.2%
Grewia densa	2.9%	*Salvadora persica*	3.3%	*Grewia densa*	3.8%

Comparing specific forest fragment results with those reported by Medley, 1991 indicated some shifts in composition in areas thought to be senescing or suffering anthropogenic disturbance, while other areas maintained similar structures over the 14 years *(Table 5)*. In TRNPR, the *Congolani* and *Mchelelo* areas, which are further from villages and closer to the Mchelelo research station, appear to have increased basal area since 1991 and kept similar species compositions. The *Mnazini forests*, near Kitere, Mnazini, and Baomo villages and farmlands, may have seen a decrease in basal area. Mnazini South, described as undergoing 'forest decline and loss due to flooding and fire' (Medley, 1991) was found to be dominated by woodland trees and shrubs in 2005, with fewer clay evergreen species like *Garcinia livingstonei* and *Mimusops obustifolia*. In TDIP Hewani East, *Barringtonia* *racemosa* and *Ficus sycomorus* appear to have gained dominance over other species. These are among the species found to be able to regenerate in Tana's changed conditions and they also have low wood density and were generally not cut for poles or timber.

Table 5 Comparison of species composition and structure in TRNPR and TDIP forest fragments observed with Medley, 1991 results

TRNPR Fragment		Medley, 1991		Glenday, 2005	
name	**number**	***species grouping***	**transect basal area** (m2/ha)	***dominant species***	**mean plot basal area** (m2/ha)
Mchelelo West	11	Hyphaene-Sorindeia-Diospyros	23	*Polysphaeria multiflora, Hyphaene compressa, Sorindeia madagascariensis*	31
Congolani Central	13	Hyphaene	23	*Polysphaeria multiflora, Hyphaene compressa, Acacia robusta*	35
Congolani West	14	Mimusops-Acacia	23	*Hunteria zeylanica, Acacia robusta, Hyphaene compressa*	35
Baomo South	22	*Synsepalum* (Pachystela) - Ficus		*Polysphaeria multiflora, Synsepalum msolo, Ficus sycomorus*	42
Mnazini North	26	*Synsepalum* (Pachystela) - Ficus	66	*Polysphaeria multiflora, Synsepalum msolo, Ficus sycomorus*	23
Mnazini South	27	Mimusops-Garcinia	66	*Lecaniodiscus fraxinifolius, Acacia robusta, Diospyros mespiliformis, (Cola minor, Garcinia livingstoni)*	38
Guru West (North)	10a	Ficus		*Ficus sycomorus, Polyshaeria multiflora, Grewia densa*	28
Guru West (South)	10b	mixed		*Thespesia danis, Drypetes natalensis, Alangium saviifolium*	25

Hewani East 3, TDIP Forest fragment 61

Medley, 1991		Glenday, 2005	
Species	**stem density** (stems/ha)	**Species**	**stem density** (stems/ha)
Barringtonia racemosa	368	*Barringtonia racemosa*	804
Synsepalum msolo	112	*Ficus sycomorus*	56
Sorindeia madagascariensis	115	*Sorindeia madagascariensis*	16
Ficus sycomorus	34	*Mimusops obtusifolia*	8
Antidesma venosum	34	*Oxystigma msoo*	8

4.2 Mapping forest cover

Spectral analyses of Landsat images (*Figure 2 & 3, Table 6*) were able to differentiate between forest cover and open areas with an overall map accuracy of 90%. Accuracy decreased to 66% when attempting to differentiate between forest, treed shamba (farmlands with mango and banana trees), woodlands, and open cover types. Plots with open canopies and some grass and dry shrub undergrowth were classified as 'woodland' and the few with those with scattered trees and dominated by grass or bare-ground were classified as 'open.' Treed farmlands were often misclassified as indigenous forest or woodland (producer accuracy: 64%, user accuracy: 54%).

Indistinct boundaries between open woodland savanna, partial canopy woodland, and closed canopy forest decreased classification accuracy (*Appendix E*). This problem was seen by Tabor et al. mapping TRNPR forest cover using satellite images: classification accuracy was lowest for transitional woodland areas (Tabor et al., 2004). Attempts were made to differentiate between levee and clay evergreen forest types spectrally, but spectral separability (Jeffries-Matusita separability index < 1.80) was too low to map these classes with any accuracy from satellite images.

Comparing TRNPR and TDIP (Table 6), the sites had similar proportions under wooded cover (70-75%). While TDIP had slightly lower proportion wooded (70%) a greater proportion of it was closed forest (28% TDIP, 23% TRNPR). Forest areas in TRNPR appeared surrounded by larger blocks of transitional woodland than TDIP where smaller forest and woodland patches were surrounded by open areas. Total estimated forest areas were greater than other estimates for TRNPR (Tabor et al, 2004) and TDIP (Cunneyworth, in Luke, Hatfield, Cunneyworth, 2005). This is likely related to boundaries drawn between woodland and forest in different studies and the inclusion here of very small forested patches not included in primate surveys.

Table 6 Land cover composition in TRNPR and TDIP areas, 2003, from Landsat classification

TRNPR: inside reserve boundary			**TDIP**: inside dyke plus 500m river buffer		
cover type	**area (ha)**	**% classified**	**cover type**	**area (ha)**	**% classified**
river	307	2%	***river***	94	2%
bare/road	223	1%	***bare/road***	124	2%
swampland	51	0.3%	***flooded field***	107	2%
open grass/ shrub/crops	6,433	39%	***open grass/ shrub/crops***	1,254	23%
open woodland/ sparse tree	1,300	8%	***open woodland/ sparse tree***	1,746	33%
shrubland	4,413	27%	***shrubland***	487	9%
woodland	2,682	16%	***woodland***	808	15%
forest	855	5%	***forest***	433	8%
treed shamba	225	1%	***treed shamba***	288	5%
Total classified	16,489		Total classified	5,342	
unknown	301	2%	unknown	85	2%

Total area	16,791		Total area	5,427	
'open'	12,420	75%	**'open'**	3,719	70%
'wooded'	3,763	23%	**'wooded'**	1,529	29%

4.3 Carbon densities of Lower Tana River forest types

In all forest types ***live tree aboveground biomass (AGB)*** was the largest carbon pool making up 45-60% of the total carbon density, while ***soils*** and ***belowground biomass (BGB)/roots*** made up 21-32% and 11-14% respectively (*Figure 3*, *Table 6*). *Litter, standing dead trees,* and *coarse woody debris* (fallen dead wood), collectively made up 5-15% of the total, while herbaceous vegetation contributed under 0.2%. The highest contribution from standing deadwood was seen in transition/woodland (5.8 Mg C/ha, 4% of total carbon)

Levee forests had the *highest mean total carbon densities* (227 ± 34 Mg C/ha, clay/levee: 257 ± 43 Mg C/ha), significantly higher than carbon densities seen in clay evergreen forests (170 ± 13 Mg C/ha) and transitional forest/woodland areas (163 ± 15 Mg C/ha). These differences are primarily the result of differences in *tree biomass density*, rather than soil carbon. As expected, mean carbon density of the sand and silt seen in levee plots (48 ± 13 Mg C/ha) was lower than on clay soils (52-55 Mg C/ha), this difference was not statistically significant and was small relative to the difference in biomass. Levee forest had higher tree densities and larger trees than the other types yielding AGB carbon densities 60-90 Mg C/ha greater than the forest types typically found further from the river.

Figure 4 Carbon densities calculated as the mean density for all sample plots in a forest class. Error bars denote 95% confidence interval for the mean total carbon density (sum of all carbon pools).

Table 7 Mean total carbon densities and carbon pool densities for forest types of the Lower Tana River, TDIP and TRNPR, 2005

Carbon densities for various forest type classifications calculated as the mean of the calculated carbon densities for inventory plots. Carbon densities and their percent contribution to the total carbon density are included for the three most significant carbon pools: live tree aboveground biomass (AGB), live tree belowground biomass (BGB) (roots), and soil. *95% confidence intervals (CI) were calculated for each mean.*

Forest class	plots sampled	Mean Carbon Density (Mg C/ha)										
		Total C	95% CI	**live tree AGB**	95% CI	*% of total C*	**live tree BGB**	95% CI	*% of total C*	**soil**	95% CI	*% of total C*
levee	27	**227**	34	**128**	30	*56%*	**31**	6	*13%*	**48**	13	*21%*
clay/levee	21	**257**	43	**155**	39	*60%*	**35**	8	*14%*	**55**	16	*22%*
clay evergreen	42	**170**	13	**79**	11	*47%*	**20**	2	*12%*	**54**	6	*32%*
transition / woodland	52	**163**	15	**74**	13	*45%*	**19**	3	*11%*	**52**	5	*32%*
Significant differences: (p < 0.05)		*both levee types greater than clay evergreen & transition/woodland*		*both levee types greater than clay evergreen & transition/woodland*			*both levee types greater than clay evergreen & transition/woodland*			*none*		
ALL TYPES	142	**191**	12	**98**	11	*51%*	**24**	2	*13%*	**52**	4	*27%*

Comparing **TDIP** and **TRNPR**, only the **transitional/woodland class** showed a significant difference by location. (To compare locations, levee and clay/levee were combined as their carbon densities were not significantly different.) Transitional/woodland mean *total carbon density* in **TRNPR** was 170 ± 10 Mg C/ha. In TDIP it was 132 ± 11 Mg C/ha. As seen in Figure 1, transitional/woodland in TRNPR had a similar size distribution shape to TDIP, but higher stem density in all size classes. This made *AGB carbon density* in TRNPR 27 Mg C/ha *more* than TDIP (p=0.04). This may reflect more advanced senescence or disturbances in TDIP. *Deadwood carbon density* was 8 Mg C/ha higher in TRNPR (p<0.001), perhaps indicating earlier stages of senescence or less dead fuelwood removal.

Carbon density values for Tana forest types fell between those reported for dry and moist tropical forests in Africa and Latin America (*Table 7*). This is consistent with mixed moist and dry forest characteristics seen in arid area riverine forests. Compared to modeled *AGB carbon densities* (estimated from biophysical properties), Tana levee forest AGB densities were between *potential densities* for **African moist forest** (206 Mg C/ha) and African forest with **seasonal rain** (105 Mg C/ha, Brown & Gaston, 1995). While there have been few published studies of carbon densities for ***tropical riverine forests***, the results for ***AGB carbon densities*** in **levee forests** were similar to those seen in reverie forests Venezuela (148 Mg C/ha, Delaney et al, 1997) and Mexico (188 Mg C/ha, Jaramillo et al., 2003).

Clay evergreen and **transition/woodland** areas had AGB carbon values close to the estimated 'actual' AGB (degraded from potential by anthropogenic influence) African forest with seasonal rain (70 Mg C/ha) and well above estimates for African dry forest (30-46 Mg C/ha, Brown & Gaston, 1995). Compared to other field studies, Tana transition/woodland and clay evergreen areas had *higher* biomass values than Southern African **woodland and savanna** (13-19 Mg C/ha, Woomer, 1993), but were more similar to those seen in closed dry forest on clay soils seen in Venezuela (Delaney et al., 1997).

Other studies reported more ***soil carbon*** than seen in Tana River, which could be due to actual soil property differences, but is also a function sampling methodology as some other studies sampled to greater depths (e.g. Delaney et al, 1997, sampled to 1m). While deeper soils do store carbon, meaning larger carbon density figures, most changes in soil carbon due to vegetation alteration and tilling occur in the topsoil. Soils in this study did have more carbon than the sandy soils of Zimbabwe's miombo woodland.

Table 8 Mean total and pool carbon densities found in other studies of riverine, dry, and African forests (See references for full citations of sources),
AGB - aboveground biomass, BGB – belowground biomass or roots, most studies only include woody vegetation with dbh > 5cm

The GIS model created by Brown & Gaston predicted **potential AGB carbon** from precipitation, climactic indices, elevation, slope, and soil texture. **Actual AGB** was predicted based on degradation ratios from potential AGB relating to population density. Models were calibrated with field data.

Continent	Country	Moisture class	description	Mean carbon density (Mg C/ ha)							Source	
				total	AGB	% of total	BGB	% of total	soil	% of total		
Africa	Kenya	**country mean**	Actual AGB estimated from GIS model		**16**	CV = 0.8					Brown & Gaston	1995
Africa	Kenya	**country mean**	Potential AGB estimated from GIS model		**29**	CV = 1.04					Brown & Gaston	1995
Africa	all tropical	**dry**	Actual AGB estimated from GIS model		**30**	CV = 1.12					Brown & Gaston	1995
Africa	all tropical	**dry**	Potential AGB estimated from GIS model		**46**	CV = 0.96					Brown & Gaston	1995
Africa	South Africa	**dry**	broadleaf savanna	94	**13**	14%	**2**	2%	**72**	76%	Woomer	1993
Africa	Zimbabwe	**dry**	miombo woodland (Brachystegia) on sand	48	**19**	40%	**4**	9%	**21**	43%	Woomer	1993
Central America	Venezuela	**dry**	Closed forest, clay soils	344	**70**	20%	**33**	10%	**233**	68%	Delaney et al.	1997
Central America	Venezuela	**dry/ moist**	Closed forest, clay/sand/silt soils	302	**148**	49%	**27**	9%	**125**	41%	Delaney et al.	1997
North America	Mexico	**dry**	deciduous, leguminous on loam soils	139	**35**	25%	**7**	5%	**76**	55%	Jaramillo et al.	2003
North America	Mexico	**dry/ floodplain**	Evergreen and deciduous on alluvial sandy soils	342	**188**	55%	**13**	4%	**114**	33%	Jaramillo et al.	2003
Africa	all tropical	**seasonal**	Actual AGB estimated from GIS model		**70**	CV = 0.71					Brown & Gaston	1995
Africa	all tropical	**seasonal**	Potential AGB estimated from GIS model		**105**	CV = 0.60					Brown & Gaston	1995
Africa	all tropical	**moist**	Actual AGB estimated from GIS model		**189**	CV = 0.22					Brown & Gaston	1995
Africa	all tropical	**moist**	Potential AGB estimated from GIS model		**206**	CV = 0.15					Brown & Gaston	1995

4.4 *Carbon density co-factors*

a. Soil characteristics, position, & distance from river

Forest type distribution in the Tana floodplain is linked to distributions of soil types, flooding and groundwater, related to distance from the river (*see Section 2*). These factors influence **carbon distribution** by dictating growth of forest types with different carbon densities (*Table 8*). *High carbon* **levee** forest was found predominantly on soils in which silt overlaid sand (indicating a flood over sand deposition) in the middle of forest patches, around 250 m from the river's edge. *Low carbon* **transition/woodland** was found on a variety of soils, mostly on forests' outer edges, and further from the river channel than levee forest.

Carbon density also varied ***within*** forest types, however physical parameters evaluated here explained little of this variation with certainty (statistical significance) at this sampling intensity. Transitional/woodland occurred on a variety of soils, but carbon densities on different soils did not differ significantly. Sand carbon density was lower than other types, but the difference wasn't significant. Similarly, **river edge** levee and clay/levee generally had *higher* carbon densities than those elsewhere, but the differences weren't significant. Edge plots **bordering open areas** had *lower* carbon density than internal areas in all forest types.

Within forest types, distance from the **river channel** only varied greatly in clay evergreen and transition/woodland areas. Carbon densities in clay evergreen forest generally *decreased* with increasing distance from the river, but the effect was only significant for soil carbon (*Table 8*). No statistically significant relationship was seen in transitional/woodland areas, consistent with the more widespread *dry conditions* that produce this cover type.

Table 9 Physical characteristics of forest types in Lower Tana River Forests and their effects on carbon density variation with forest types

'Significant': statistically significant effect on carbon density with $p < 0.1$

Forest type	**soil type** (% of plots)					**forest edge** (% of plots)			**distance to river/channel**
	clay	*clay on silt*	*silt on clay*	*silt on sand*	*sand*	*river edge*	*plot borders open vegetation*	*middle*	*Mean plot distance (m)*
levee	0%	7%	0%	**93%**	0%	35%	25%	**75%**	246*
effect carbon density	little soil type variation: no significant effects on C					river edge: highest soil C; open area edges: lowest tree & soil C; not significant			few outside 400m, max C around 200 m, no significant relationship
clay/levee	**33%**	0%	**58%**	8%	0%	24%	**59%**	41%	180*
effect carbon density	soils mostly clay types: no significant effect on C					river edge: highest C; open area edges: lowest C; not significant			few outside 200 m, no significant relationship
clay evergreen	**45%**	0%	**31%**	24%	0%	0%	52%	48%	641[#]
effect carbon density	soils mostly clay types: no significant effect on C					open area edge: lowest tree C, significantly lower soil C (10 Mg C/ha)			decreasing soil C ($r2=0.14, p=0.05$) decreasing tree, not significant
transition/ woodland	13%	3%	44%	31%	9%	11%	**64%**	36%	480[#]
effect carbon density	varied soil types: sand had lower soil C, not significant					river edge: high tree C & low soil C; open area edge: low tree C, not significant			wide spread of distances, no significant relationship

* significantly different mean from [#] $p<0.05$

b. Anthropogenic disturbance

Felling of *medium to large trees* (dbh ≥ 20 cm) was seen to be ongoing in both the TDIP and TRNPR areas although it was less common than polewood/fuelwood harvesting (*Table 10*). Surprisingly, tree cutting was found to be *more* common in the TRNPR forests than in the TDIP area and more areas of complete forest clearance were seen in TRNPR (*Figure 5*). Observed stumps were most frequently *Mimusops obustifolia*, *Synsepalum msolo*, and *Ficus sycomorus*. Stumps in TRNPR were more often seen in the northern and southern parts of the reserve, closer to villages and further from the centrally located KWS station and research camp. **Polewood and fuelwood harvesting** was widespread across both areas with a high frequency (in 79-83% of inventory plots).

Recent **forest clearing**, in which all larger trees had been felled and the surrounding area burned, leaving stumps and bare ground, was seen in a few areas along the river banks in TDIP, but was more frequently observed in TRNPR. Clearance of TRNPR forest was seen in old oxbow depressions, along riverbanks, and even in the middle of forest patches, predominantly in the northern areas of the reserve. It should be noted that felling and clearing has occurred in forests around Baomo (Baomo North, 21) in TRNPR but the area was not considered safe to inventory. Much of the clearing observed was very recent, burned areas still smoking or with maize seedlings or banana saplings growing around fresh stumps, meaning that these areas appeared as forest in 12/2003 satellite image.

Forest clearing reduces the carbon stock of the landscape, but tree felling at unsustainable rates can also reduce carbon stock by reducing the carbon density of the forest. Inventory plots with stumps in them had lower mean *AGB carbon densities* than those without stumps across all forest types (8 Mg C/ha less in levee and clay evergreen, 27 Mg C/ha in transition/woodland, *Figure 6*). However, except for the transitional/woodland plots, statistically significant differences in AGB carbon couldn't be established at this sampling intensity (low proportions of inventory plots contained stumps). The effects of pole/fuelwood harvesting on carbon densities were neither sizeable nor statistically significant.

Table 10 Anthropogenic disturbances observed in TDIP and TRNPR forests, 2005

fresh – appearing to have occurred in past 6 months **old** – appearing to have occurred more than 6 months ago. All stumps and cut branches with significant sprouting were deemed 'old.'

forest type	% of plots with evidence of anthropogenic disturbance within 200 m					
	old med-large cut stumps (>20 cm dbh)		**fresh med-large cut stumps** (>20 cm dbh)		**polewood cutting** (3-20 cm dbh)	
	TDIP	**TRNPR**	**TDIP**	**TRNPR**	**TDIP**	**TRNPR**
levee	0%	21%	0%	25%	100%	71%
clay / levee	0%	0%	0%	50%	74%	100%
clay evergreen	4%	16%	5%	37%	91%	79%
transition / woodland	6%	20%	6%	14%	82%	83%
ALL	***3%***	***19%***	***3%***	***24%***	***83%***	***79%***

Figure 5 Anthropogenic disturbances in and en route to inventory plots were GPSed in the field. Pole and fuelwood harvesting was seen in roughly 80% of plots and so was not included on the maps.

Figure 6 Carbon densities estimated from means of inventory plots in each forest type. Error bars indicate 95% confidence interval. AGB = aboveground biomass from trees

By estimating former biomass of cut trees for fresh stumps in inventory plots, **mean AGB carbon loss from recent cutting** was calculated. It was estimated that the forested areas of TDIP lost 0.3 ± 0.2 Mg C/ha over the six months preceding the study and the TRNPR lost 0.9 ± 0.4 Mg C/ha, meaning annual losses of 0.6 ± 0.4 Mg C/ha and 1.8 ± 0.8 Mg C/ha due to logging of medium/large trees (dbh ≥ 20 cm). This is also very likely an ***underestimate***: it leaves out cut trees with dbh under 5 cm and the carbon inventory plot structure, in which small trees/stumps were measured in small subplots, was not designed to accurately capture dispersed cutting of small trees.

The percent of the extracted biomass that was burned as fuel is unknown. Carbon accumulation rates for young floodplain forest in Costa Rica were found to be 0.35 Mg C/ha while mature moist forests accumulated at a rate of 1.3 Mg C/ha (Clarke, 2000). If the forests of the lower Tana River are assumed to have similar growth rates, it is possible that the region is actually **emitting carbon** due to removal and burning of forest trees.

c. TDIP vs. TRNPR

Mean carbon densities in **levee** and **clay evergreen** types in TDIP and TRNPR were not sizably or significantly different, despite management, disturbances, and river channel differences. However, of forest plots sampled, a greater proportion sampled in TDIP were classified as clay evergreen (37%) than levee compared to TRNPR (24%). The 'clay evergreen' class, with its lower carbon density, was thought to be the senescent phase of riverine forests that no longer have the water supply to maintain moist 'levee' forest (Medley, 1992).

Transitional forest / woodland areas sampled in TRNPR (178 Mg C/ha) did have greater mean carbon densities than those in TDIP (131 Mg C/ha) due to significantly *greater* tree AGB, soil, and deadwood carbon in the TRNPR transitional forests / woodland. Transitional forest / woodland areas were seen in closer to the river channel TRNPR than in TDIP, with the mean plot distance to the river being 776 m closer to the river in TRNPR, and soil carbon and biomass were seen to increase closer to the river. TRNPR areas of this type also had more trees in larger size classes (Figure 1). These carbon changing differences may reflect senescing of TDIP forest cut off from the river, differential effects of 1997 El Nino flooding, and/or human use of transitional/woodland areas (fuelwood, grazing, burning).

4.5 TDIP plantation carbon

A few areas originally earmarked for tree plantations in TDIP were planted with *Senna siamea*, *Eucalyptus* species, *Azadirachta indica*, and *Mangifera indica* were planted in the early 1990s and a few survived the 1997 El Nino, although damaged. These were sampled to compare carbon densities with the forest. The variation of ages, planting densities, management, and flooding damage made the carbon densities difficult to compare, but plots planted 10-15 years ago stored 60-80 Mg C/ha (*Figure 7*), about half the carbon density of transitional woodland areas. Both soil and live tree carbon densities were lower than forested areas. Roughly estimating growth by dividing AGB carbon density by estimated age yielded **carbon accumulation rates** ranging from 4 Mg C/ha/yr for *Eucalyptus* spp to 8 Mg C/ha/yr for *A. indica.* This is inline with estimated accumulation rates for tropical species woodlots planted in Panama, 4-5 Mg C/ha/yr (Losi et al., 2003).

Figure 7 Carbon densities for individual sample plots in plantation areas.

4.6 Total carbon stock and changes over time

a. Carbon stock

Total carbon stock, for the 12/2003 land cover composition, was estimated using mean carbon densities from plots classified as *forest* (both levee and clay as well as closed canopy areas with transitional species), *woodland* (partially open canopy, partial grass cover), and *open woodland savanna* (open, grass dominated). *Shrubland* areas were assigned the mean carbon density of plots dominated by low (5m and under) woody shrubs and *treed shamba* areas were assigned the mean mango plantation value. Areas without significant woody growth were assigned values from soil samples taken in fields and grasslands.

Table 11 Calculating carbon stock for the TDIP & TRNPR areas using land cover compositions 12/2003

TDIP area		*Midrange estimate*				*High value estimate*				*Low value estimate*			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI
bare/road	124	19	3	0.002	0.000	19	3	0.002	0.000	19	3	0.002	0.000
field (flooded)	107	29	4	0.003	0.000	29	4	0.003	0.000	29	4	0.003	0.000
open grass/ shrub/crops	1,254	29	4	0.04	0.005	29	4	0.04	0.005	29	4	0.04	0.005
open woodland /sparse tree	1,746	125	35	0.22	0.06	125	35	0.22	0.06	90	17	0.16	0.03
shrubland	487	90	17	0.04	0.008	125	35	0.06	0.02	90	17	0.04	0.008
woodland	808	138	10	0.11	0.008	138	10	0.11	0.008	138	10	0.11	0.008
forest	433	222	18	0.10	0.008	222	18	0.10	0.008	222	18	0.10	0.008
treed shamba	288	165	7	0.05	0.002	207	27	0.06	0.008	165	7	0.05	0.002
Total (Tg C)				**0.56**	0.06			**0.59**	0.07			**0.50**	0.03

TRNPR		*Midrange estimate*				*High value estimate*				*Low value estimate*			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Tg C)	95% CI
bare/road	223	19	3	0.004	0.001	19	3	0.004	0.001	19	3	0.004	0.001
field (flooded)	51	29	4	0.001	0.000	29	4	0.001	0.000	29	4	0.001	0.000
open grass/ shrub/crops	6,433	29	4	0.19	0.03	29	4	0.19	0.03	29	4	0.19	0.03
open woodland /sparse tree	1,300	125	35	0.16	0.05	125	35	0.16	0.05	90	17	0.12	0.02
shrubland	4,413	90	17	0.40	0.08	125	35	0.55	0.15	90	17	0.40	0.08
woodland	2,682	138	10	0.37	0.03	138	10	0.37	0.03	138	10	0.37	0.03
forest	855	222	18	0.19	0.02	222	18	0.19	0.02	222	18	0.19	0.02
treed shamba	225	165	7	0.04	0.002	207	27	0.05	0.006	165	7	0.04	0.002
Total (Tg C)				**1.4**	0.1			**1.5**	0.2			**1.3**	0.1

Due to uncertainties in estimates for less sampled and less accurately mapped cover types, a **high value estimate** was calculated using open woodland value for shrubland areas and the mean value of all plots spectrally classed as treed shamba for the treed shamba areas. A **low value estimate** was calculated using the shrubland value for the open woodland savanna as this value better matched values estimated for open woodlands in Southern Africa (94 Mg C/ha: Woomer, 1993).

The TDIP area, the area bounded by the dyke plus the associated 500m riverine buffer, stored 0.50-0.60 Tg C on roughly 5,300 ha of land. The TRNPR reserve area stored 1.3-1.5 Tg C on roughly 16,500 ha.

b. Changes in carbon stock over time

Carbon stocks in both the TDIP and TRNPR areas have declined in past decades with the loss of forest cover (*see section 2.3*). While other studies have estimated the loss of closed forest cover, focusing primarily on loss of endangered primate habitat, there has been less assessment of the transition to woodland and/or to more open cover types needed to quantify terrestrial carbon stock has been lost. Forest cleared for agricultural use or forest lost to intense flooding will result in a fast transition to cover types with low carbon densities, but forest slowly senescing into woodland and savanna as they lose access to water transition through medium carbon density cover types over periods of decades.

Overlaying a land cover classification for 1992 with the 2003 cover gave an indication of where and how much wooded cover had been lost in both areas (*Figure 8, Table 12*). However, due to 30% cloud cover in the 1992 image and the indefinite boundaries between forest and woodland areas which may be exacerbated by using images taken in different seasons: June (end of rains), 1992 vs. December (end of short rains) 2003, *these figures must been as an illustration of the magnitude of change rather than definitive measurements.*

Table 12 Land cover change and estimated carbon stock changes in clearly classified areas of TDIP and TRNPR 1992 – 2003 Areas of cloud, river, or unknown cover in either image were not included.

1992 -2003 cover change	**TDIP**			**TRNPR**		
	area (ha)	**carbon density change** (Mg C/ha)	**carbon stock change** (Mg C)	**area** (ha)	**carbon density change** (Mg C/ha)	**carbon stock change** (Mg C)
forest to open	143	-130	-18,590	161	-130	-20,930
open to forest	119	130	15,408	6	130	780
net deforestation	***-24***		***-3,182***	***-155***		***-20,150***
forest to woodland	120	-80	-9,589	188	-80	-15,040
woodland to forest	98	80	7,856	157	80	12,560
net senescence to woodland	***-22***		***-1,733***	***-31***		***-2,480***
woodland to open	816	-50	-40,785	726	-50	-36,300
open to woodland	334	50	16,700	131	50	6,550
net opening of woodland	***-482***		***-24,085***	***-595***		***-29,750***
Change in carbon stock (Mg C)			**-29,000**			**-52,400**

The TRNPR lost roughly 20% of its wooded cover (woodland and forest) from 1992-2003, likely reducing carbon stocks by 50,000 Mg C or more. Most of the closed forest loss in TRNPR from 1992 to 2003 appears to be conversion to low carbon density open cover types, occurring along the river edges in the north of the reserve and south of Baomo village (forests 21-22). These observations are consistent with the continued clearing observed in these areas during 2005 sampling and with Tabor et al.'s observation that much of the clearing from 1992-2000 had occurred in the northern end of the reserve (Tabor et al., 2004). Tabor et al. estimated a 10% loss of forest cover from 1992-2003, consistent with the 15% loss of forest cover from 1992-2003 seen in these maps.

In the TDIP area, 30% of the wooded area was converted to open cover from 1992-2003, likely reducing carbon stocks by 29,000 Mg C. Most of this loss was the conversion of woodland to open cover. Much of the lost closed forest was converted to woodland, possibly indicating forest senescence due to dehydration or damage done in the 1997 flood. There was some conversion of forest to open cover along the river edge and edges of forest fragments.

5. Conclusions: Potential for carbon offset projects

5.1 Potential to increase carbon stocks

Terrestrial carbon stocks can be expanded by increasing the *area* with high carbon density cover types and by increasing the *carbon density* of cover types. While there is potential for both these activities to increase carbon storage in the Lower Tana River Forests, increasing the area of treed cover was found to be the most likely to make substantial, quantifiable, and hence tradable, increases in carbon stocks.

a. Increasing *carbon densities*

Increasing *carbon density* in forest and woodland areas could be achieved by:

- reducing the extractive use of forest products,
- employing low impact logging techniques when trees are harvested,
- enriching low density forest areas by planting seeds or seedlings

Areas in which *large and medium sized trees* had been felled had lower carbon densities by roughly 8 Mg C/ha than areas without noticeable logging. Biomass removals from logging were similar to tropical riverine forest carbon accumulation rates. However, it has been reported that large trees are predominantly felled for **non-fuel timber products** such as building or canoe making (Medley, 1992). This means much of this wood is not burned and continues to act as terrestrial *carbon store* and if new trees grow in the place of those harvested for non-fuel products, the capacity of the forest to continue sequestering carbon won't be compromised. However, *natural regeneration* in the Tana River area has seen to be low especially with changes in the river dynamics, so tree felling is likely to have a greater influence on carbon stocks in the future.

The results of this study indicated that areas where *polewood and fuelwood harvesting* (small trees and branches cut) was observed did *not* show significantly lower carbon densities than areas not harvested. This is consistent with earlier observation that use of forest products on the whole had not seriously deteriorated forest structure (Medley, 1992). However, in

1990 it was estimated that the villages around TDIP consumed a total of 25 Mg of wood per week (Maitha et al., 1990), which translates to roughly 0.18 Mg C/ha/yr extracted if it is all taken from TDIP shrubland, savanna, woodland, and forest (*Appendix F*). This is approaching the under 0.3 Mg C/ha/yr assumed carbon accumulation rate (Clarke, 2000). It is clearly possible that continued harvesting for pole and fuelwood may begin to noticeably impact carbon densities as resources are depleted, populations grow, and more forest area senesce.

Fuelwood use efficiency technologies (such as energy efficient stoves) would both reduce carbon emissions from fuel burning and reduce cutting, hence increasing carbon densities. **Enrichment planting** in gaps created by tree felling could ensure regrowth after harvesting and maintain or enhance forest carbon density. The carbon benefits from planting in scattered forest gaps may be difficult to monitor and quantify with sufficient accuracy sell carbon credits, however other funding avenues could be sought. Forest areas damaged by El Nino were found to have lower carbon densities and woodland characteristics despite being relatively close to the river channel (e.g. Mnazini South 27, Kulesa East 48, and Wema East 56 had areas spectrally classified as woodland, low carbon densities, and transitional species compositions). These larger consolidated damaged areas may be better suited to enrichment planting.

b. Increasing *high carbon density cover areas*

Both the TDIP area and TRNPR lost forest and woodland cover from 1992-2003 and clearance appeared to be ongoing in 2005. Previous reports indicate net forest loss between 1960 and 1990 (*Table 3*), however the different methods of delineating forest prevent accurate cross study calculations. If it were possible to reforest areas that lost tree cover just in 1992-2003, the carbon stock gains for TDIP would be in the range of 29,000 Mg C worth roughly $116,000 (at $4/Mg C certified emission reduction) and for TRNPR would be in the range of 50, 000 Mg C worth roughly $200,000. While it may be biophysically possible to establish tree cover on even more land, there are multiple restrictions on ‘available’ area.

Reforestation and afforestation in the Lower Tana River forests is complex as the areas ‘available’ for high carbon density cover types are determined by both the river course and the demand for agricultural land by local communities***. It cannot be assumed that all forest lost can be feasibly regained.*** Some of loss of forest and woodland cover in past decades has been the result of forest senescence due to altered river dynamics due to upstream dams, irrigation, floods, and droughts. Because of the decrease of low intensity flooding that brings water and nutrients, areas that area protected from use may not regenerate naturally.

In addition, riverside levees, which are the prime areas for reforestation because they support the highest carbon density forests, are also the most desirable farmland. **Alternative income projects** and increasing **land use efficiency** where possible could make more area available, but it is not likely that all areas that could support levee forest could be made available for afforestation and reforestation and still meet community needs. However, farmers could be encouraged and assisted in planting trees directly along riverbanks to prevent erosion.

Reforestation efforts will likely require planting and perhaps extensive watering in areas at greater distances from the river. Further from the river channel, planting **dry-tolerant species** (species like *Acacia robusta*, that survive and regenerate in clay evergreen and transitional woodland areas), although they store less carbon, may reduce the watering requirements. Initial planting **fast-growing** trees, like early successional species such as *Ficus sycomorus*, would initiate carbon gains and possible credit sales at earlier dates and may ameliorate soil and shade conditions for future plantings of higher wood density species.

Carbon credit sales reinvested in the community would help make an afforestation / reforestation project beneficial to local interests, but the incorporation of **agroforestry** and **woodlots** into a carbon project areas could both increase carbon stocks, meet local resource needs, and reduce extraction from forest areas:

- Trees with **non-timber products** such as fruits, seeds, leaves, or bark provide both carbon storage and economic or subsistence produce. Mangos (*Mangifera indica*) are one such crop already prominent in the area, however supplies appear to have saturated local markets, illustrating the need to promote both the crop and the market for its goods.
- Trees with **non-fuel timber products** already in demand, such as indigenous species used for building materials, poles, and canoes, can both sequester carbon as they grow and store it in the timber product itself. Continuous replanting in rotations can also ensure a constant carbon stock in the plantation area. It should be noted that some timber species (such as *Eucalyptus spp* that can deplete soil nutrients) and some management techniques (large scale clear-felling on slopes, burning of unused material) can actually result in net carbon loses.
- **Fuelwood plantations** can store carbon if carefully managed so that areas are continuously replanted in rotation and the rate of tree growth carbon accumulation is greater than or equal to the rate of burning. This is difficult to achieve with high fuelwood demand and thus almost exclusively requires the use of fast growing species, which are often exotic.

Plantations tend to have lower maximum carbon storage than the dense and more constant vegetative cover of indigenous forest, but the benefits of their produce help ensure project sustainability. In addition, current agricultural areas would be 'available' for agroforestry, plantations, and woodlots, that wouldn't be effectively available reforestation.

Carbon stock increases from **tree planting on farms** will be determined by the species planted, tree growth rates, tree species effects on soil pool, harvesting rates for timber or fuel, the number of land holders participating, the number of trees each can grow successfully, and added regeneration benefits from reducing pressure on ASF. Managing and accounting for carbon stocks accrued by separate landholders can pose a challenge. However successful agroforestry carbon offset projects, such as TIST (*Table 1*) have been able to tackle this problem through small group tree planting commitments and group self-monitoring programs.

5.2 Potential to attract project funding

A variety of activities could increase carbon storage in the Lower Tana River areas assessed, however this does not guarantee that these activities will receive carbon funding. In order sell emission-offset credits for the carbon stored in a project, it has to be ascertained that this carbon was **additional**: it would not have been stored without the project activities. It must also be shown that the carbon stored in the project area did not **'leak'** meaning that project activities that increased carbon stocks in one place did not decrease them in another place. The project would then need to find a buyer for the carbon credits.

In TRNPR or TDIP net forest clearance and senescence as well as fuelwood harvesting appeared to be continuing without evidence of significant or effective activity or incentive to counteract them. A **baseline scenario** of carbon stocks in these areas, without any added tree planting or protection incentives, may be reasonably be assumed to maintain current carbon stocks if not have them continue to be depleted. Reforestation efforts in TRNPR in 2000 had failed and been abandoned for lack of funding. Preventing further forest clearance was part of suggested TARDA activity in TDIP, but no forest monitoring was underway and no effort was being made to replant damaged areas at the time of study. While economic profit could drive communities to plant agroforestry species, it is likely that high poverty levels and uncertain tenure in the area would continue to prevent local residents from making the initial financial and labor outlay for such endeavors with very delayed profits. Government agricultural interests for TDIP are currently set on rice and sugar cane rather than any tree crops. It was therefore assumed that assisted tree planting, prevented clearing, improved land and wood resource use management would be considered '**additional**' to baseline scenarios.

Projects established in TDIP and TRNPR area which restricted people's access to needed land and resources without addressing these needs in a different way could result in carbon '**leakage**' as community members would simply have to cut or clear somewhere else. Some activities that would help prevent 'leakage' include:

- Fostering alternative incomes and resource options through agroforestry, woodlots, and market building
- Initiating community participatory forest management (PFM) of designated forest use zones with sustainable harvest plans
- Disseminating fuelwood saving techniques and technologies
- Improving agricultural land use efficiency where possible

Projects have to **compete for funding** either from those buying CERs through the CDM or from the voluntary carbon market, including carbon trust funds, charitable and aid organizations, and voluntarily participating industries (e.g. those in the USA). During this commitment period of the Kyoto Protocol (2008-2012), *only tree planting afforestation and reforestation (AR) projects will be considered for land cover CDM projects*. In addition, only reforestation of areas that lost forest cover before 1990 can receive CERs through the CDM. Reforestation of area deforested post 1990, improved land management, and deforestation prevention activities can receive carbon funding from voluntary markets.

The net carbon stock increases likely for the TRNPR and TDIP areas (0.03-0.05 Tg C) are relatively small compared to most currently funded AR projects (*Table 1*). However a simplified methodology for **small-scale AR projects** (SSC-AR) will be set up for the CDM for projects with net carbon benefits 2,000 Mg C/yr (8,000 Mg CO_2/yr) or less. These simplified baseline and monitoring methods will increase the attractiveness of small projects. In addition carbon trustfunds like Plan Vivo Trust and other organizations like Clean Air Action Corporation will fund several small projects and **bundle** the carbon credits for later sale.

The TDIP and TRNPR areas have several resources and advantages that make them **attractive locations** for investors looking to promote carbon storage projects:

- High levels of biodiversity, adding value for ecologically concerned investors
- Obvious immediate need for reforestation, forest preservation, and agroforestry activities to prevent erosion, protect habitats, and maintain resources in this semi-arid area
- Relatively well researched forest types with high carbon densities compared to most arid and semi-arid areas
- A local reliance on forest resources and agroforestry species like mangos ensuring local relevance and precedence for tree planting activity
- Local communities that have expressed willingness to promote forest preservation and restoration if given needed support, allowed involvement, and allowed controlled forest access (1992 TRNPR farmer interviews, Gachugu, 1992; 2005 TDIP community interviews, Hatfield in Luke, Hatfield, Cunneyworth, 2005)

- Centralized bodies with mandates to manage the areas with respect to environmental and community interests (KWS and TARDA)
- National and international environmental organizations with significant research backgrounds in the area (e.g. Conservation International, Colobus Trust, KWS)
- Several comprehensive surveys, management assessments, and planning documents containing environmental assessments and maps (e.g. KWS-GEF, TDIP EIA, CEPF, PhD dissertations & published research), reducing effort needed to produce project design documents, baselines, and monitoring plans
- Ecotourism opportunities to create multiple income streams for a project: established tented camp in TRNPR and TDIP's accessibility to established tourist destinations – Lamu and Malindi.

There are some inherent aspects of these areas that provide **challenges** that would need to be addressed in establishing an effective carbon storage project in the area, such as:

- A variety of forest and soil types potentially increasing the research and monitoring efforts needed, such as establishing growth rates and determining the most effective planting regimes.
- A reliance on the Tana River flow as the water supply for tree growth making the necessary contingency plans for predicted river channel migration, climate change effects on river flows, deforestation in Mt. Kenya and the Aberdares as the Tana River's watershed, and possible future dams and withdrawals upstream.
- Growing demand for agricultural land and food scarcity potentially making long-term benefit projects like tree planting a lower priority for local communities
- Complex land tenure arrangements with TARDA or government land, trustlands, and reserve areas

These would not prohibit the establishment of a carbon storage project, but would need to be taken into account in project design and such a project will need an investor willing to make a long-term commitment.

5.3 Project scenario: Reforesting corridors in TDIP

A recent environmental analysis of forests in the TDIP area suggested **reforestation corridors** as a means to increase habitat connectivity for endangered primates as well as expand the resource base for local communities (Luke, Hatfield, Cunneyworth, 2005). The reforestation of these corridors (*Figure 8*) has been assessed as a potential carbon offset project to illustrate possible carbon gains of reforestation projects in the area.

Three corridors were proposed - 'Lango/Hewani/Baandi' (connecting forests 64, 63, 67), 'Bvumbwe/Wema' (56, 68, 66), 'Sailoni/Kulesa' (48, 65) - as well as a 30m riverine buffer, to be reforested by planting species common to each fragment starting at forest edges interspersed with species commonly used for forest products and agroforestry species (Luke, Hatfield, Cunneyworth, 2005). To estimate added carbon storage that this might accrue, areas of open cover in corridors were assumed to achieve the mean forest cover carbon density seen in the already forested, dry clay evergreen and transitional areas inside the corridors (172 ± 26 Mg C/ha). Open areas in riverine buffers were assumed to achieve the average carbon density for all forest (222 ± 18 Mg C/ha). River and bare/road areas were assumed not to change. These target carbon densities are higher than those seen in most of the sampled plantation areas (Figure 7), but these plantations had not reached maturity.

Table 13 Calculating increased carbon storage increase in reforestation corridors

Lango/Hewani/Baandi		2003 carbon stock				Reforestation scenario			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Mg C)	95% CI	**carbon density change** (Mg C/ha)	95% CI	**carbon stock change** (Mg C)	95% CI
bare/road	8	19	3	154	23	0	0	0	0
flooded field	2	29	4	73	11	143	19	355	46
open grass/shrub/crops	161	29	4	4,687	703	143	19	22,923	2,985
open woodland/sparse tree	270	90	17	24,211	4,609	82	22	22,202	5,874
shrubland	47	90	17	4,238	807	82	22	3,886	1,028
woodland	176	138	10	24,405	1,690	34	20	5,938	3,510
forest	53	172	26	9,067	1,387	0	0	0	0
treed shamba	11	165	7	1,748	76	0	0	0	0
TOTAL AREA	**728**			**68,584**	5,213			**55,304**	7,536

Bvumbwe/Wema		2003 carbon stock				Reforestation scenario			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Mg C)	95% CI	**carbon density change** (Mg C/ha)	95% CI	**carbon stock change** (Mg C)	95% CI
bare/road	3	19	3	59	9	0	0	0	0
flooded field	0	29	4	0	0	143	19	0	0
open grass/shrub/crops	115	29	4	3,366	505	143	19	16,463	2,144
open woodland/sparse tree	74	90	17	6,681	1,272	82	22	6,126	1,621
shrubland	8	90	17	690	131	82	22	633	167
woodland	68	138	10	9,464	655	34	20	2,303	1,361
forest	27	172	26	4,585	701	0	0	0	0
treed shamba	9	165	7	1,494	65	0	0	0	0
TOTAL AREA	**305**			**26,338**	1,678			**25,524**	3,017

Sailoni/Kulesa		2003 carbon stock				Reforestation scenario			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Mg C)	95% CI	**carbon density change** (Mg C/ha)	95% CI	**carbon stock change** (Mg C)	95% CI
bare/road	5	19	3	92	14	0	0	0	0
flooded field	0	29	4	11	2	143	19	53	7
open grass/shrub/crops	31	29	4	901	135	143	19	4,409	574
open woodland/sparse tree	39	90	17	3,502	667	82	22	3,211	850
shrubland	33	90	17	2,947	561	82	22	2,702	715
woodland	60	138	10	8,335	577	34	20	2,028	1,199
forest	54	172	26	9,336	1,428	0	0	0	0
treed shamba	14	165	7	2,247	98	0	0	0	0
TOTAL AREA	**236**			**27,371**	1,778			**12,403**	1,732

30 m River buffer		2003 carbon stock				Reforestation scenario			
cover type	**area** (ha)	**carbon density** (Mg C/ha)	95% CI	**carbon stock** (Mg C)	95% CI	**carbon density change** (Mg C/ha)	95% CI	**carbon stock change** (Mg C)	95% CI
bare/road	9	19	3	178	27	0	0	0	0
flooded field	0	29	4	0	0	193	11	0	0
open grass/shrub/crops	3	29	4	99	15	193	11	651	38
open woodland/sparse tree	20	90	17	1,818	346	132	18	2,680	355
shrubland	21	90	17	1,920	366	132	18	2,831	375
woodland	13	138	10	1,844	128	84	14	1,115	184
forest	62	222	18	13,653	1,116	0	0	0	0
treed shamba	51	165	7	8,378	366	0	0	0	0
TOTAL AREA	**180**			**27,889**	1,284			**7,277**	550

Under these assumptions, reforesting these areas would store roughly 0.10 Tg C (100,000 Mg C) with carbon credits worth roughly $400,000. Changing assumed potential carbon densities to lower, woodland values or to higher, mean forest values (including both levee and clay areas (222 ± 18 Mg C/ha) indicated that reforestation of these corridors could reasonably have a carbon storage benefit between 0.09 and 0.15 Tg C ($360-600 thousand).

Without site-specific carbon accumulation data it was assumed that rates would fall somewhere between those found for in young tropical floodplain forest (1.3 Mg C/ha/yr, Clarke , 2000) and tropical plantations (4 Mg C/ha/yr, Losi et al., 2003), indicating that it would take 30-50 years to accumulate this extra carbon ($10,000/yr from carbon credits). Unless the project had other sources of income, such as sales of agroforestry products, ecotourism revenue, or donations from aid organizations, this would have to cover all costs of the reforestation, monitoring, leakage prevention, and carbon credit validation activities. Assessment of the project costs area beyond the scope of this analysis, but would be the next step in project design.

Projects of this magnitude have been funded in the past (Table 1) through voluntary carbon markets and would also qualify for the small-scale AR simplified methodologies to get CDM CERs. Assuming 1.3 Mg C/ha gained on 1,550 ha of open cover in these areas, the project would accumulate 1,900 Mg C/yr, just under the 2,000 Mg C/yr requirement for SSC-AR. The majority of the area to be forested these corridors was not deforested in 1992-2003 (Figure 9), so it is likely that the pre-1990 requirement would not bar this project from CDM participation.

6. Recommendations: next steps

There is evident potential to increase carbon stocks in TDIP and TRNPR and activities to implement would be additional to baseline scenarios. However in order to evaluate the viability of attaining carbon funding for specific project activities and areas must be delineated. Interested partner organizations and community groups would need to meet and discuss possible location and reforestation, plantation, agroforestry, and sustainable use options and the costs and benefits of these. The carbon densities in this study could then be used to estimate carbon storage benefits the project could accrue as seen above.

There are several important areas of uncertainty in this study that should be addressed to compile a project design document:

- Forest carbon accumulation rates for different forest and plantation types given existing water availabilities.
- Information on nursery and planting soil, water, and shade requirements for the species to be planted
- A soil type distribution map as different soils support different species. Particularly needed for the very varied TRNPR area as the TDIP area is predominantly clay.
- Improved accuracy (could be achieved with aerial photography) and more current forest cover maps needed to clarify forest/woodland transition areas and keep abreast of recent forest clearing.

Increasing continuous and systematic land cover data collection and processing in and around TDIP and TRNPR would be a necessary next step to keeping track of carbon stocks, establishing monitoring protocols for carbon storing activities, submitting baselines and project forecasts, and attracting project sponsors. Forest habitat monitoring was part of both TDIP and TRNPR management plans, but these have not been upheld. Should incentives to revive/initiate regular monitoring arise, there are several ways future data collection could better help forest management and also refine carbon stock and stock change detection:

- Continuous sampling of **permanent sample plots (PSP)** every 5-10 years
    - Ensure **distribution** of PSPs includes various forest types, regenerating, senescing areas
    - Mark **individual trees** within PSPs with numbered tags so that growth increments can be collected at the individual tree level over time. This also allows for analysis of growth by species, soil type, climate conditions, etc.
    - Engagement of local communities in this process, especially if establishing **PFM** and sustainable offtake levels.
    - Calculate **cost of monitoring effort vs. precision attained** to determine suitable monitoring effort

- Additional sampling of **regenerating areas and natural recruitment** at shorter time intervals to explore growth rates and associated factors.

- **Nursery and on farm data collection and experiments** for **indigenous and agroforestry species** to determine growth rates, potential for intercropping, and other optimal conditions for reforestation and on-farm planting activities.
    - **Collection of pre-existing knowledge** of growth and suitable conditions of these species from local area residents, other research, and published sources. .

- Updating carbon relevant data collection in future **socioeconomic and resource use surveys.** For example, determining the more recent fuelwood and building material demand levels

- Improved **data mining, data management, and data storage** at TARDA and KWS
    - Creation of **standardized data collection sheets and calculation templates** with clearly recorded methodologies and metadata
    - Entry of all ***raw data*** into a **computer database**
    - **Mine past surveys and reports** for relevant data and results and including this data in the computer database for easy comparison.

- Request future **outside researchers** that intend to collect relevant data to enter their data in the database and provide them with appropriate data collection templates to facilitate this.
- **Ongoing maintenance** and **public posting of monitoring results** to collaboratively assess change and appropriately target interventions at key locations.

The TRNPR Mchelelo Research Station, the TDIP head office, KWS, and TARDA were seen to have personnel capable of carrying out these functions and training others to do so if given support and incentives. Indeed community members assisting in this study were seen to have a wealth of knowledge about their local forests and their involvement in monitoring and project design would provide employment and valuable insight. In addition, local schools, university students, volunteers, and ecotourist groups could be engaged to help conduct the data collection or management at low cost, if sufficiently organized. Initiating a cohesive database at this stage is likely to save time and investment in the future. This type of data and data management are needed for the accurate monitoring of carbon stocks and marketing of carbon credits and will also be invaluable in sustainably managing these areas.

With or without an investor interested in CERS, investing in tree planting and sustainable use activities in the Lower Tana River forests will enhance carbon stocks, increase Kenya's carbon sinks, positively influence the global and local climate, and bring the many benefits agroforestry and ecosystem services of high quality forest. Reforestation, agroforestry, and monitoring activities could provide both employment and resources for local communities. Monitoring activities would also reduce future expenditures for Kenya, as developing nations may be required to monitor its GHG emissions. The costs of carbon emission mitigation will increase as time passes as forests continue to be exploited and cleared at unsustainable levels.