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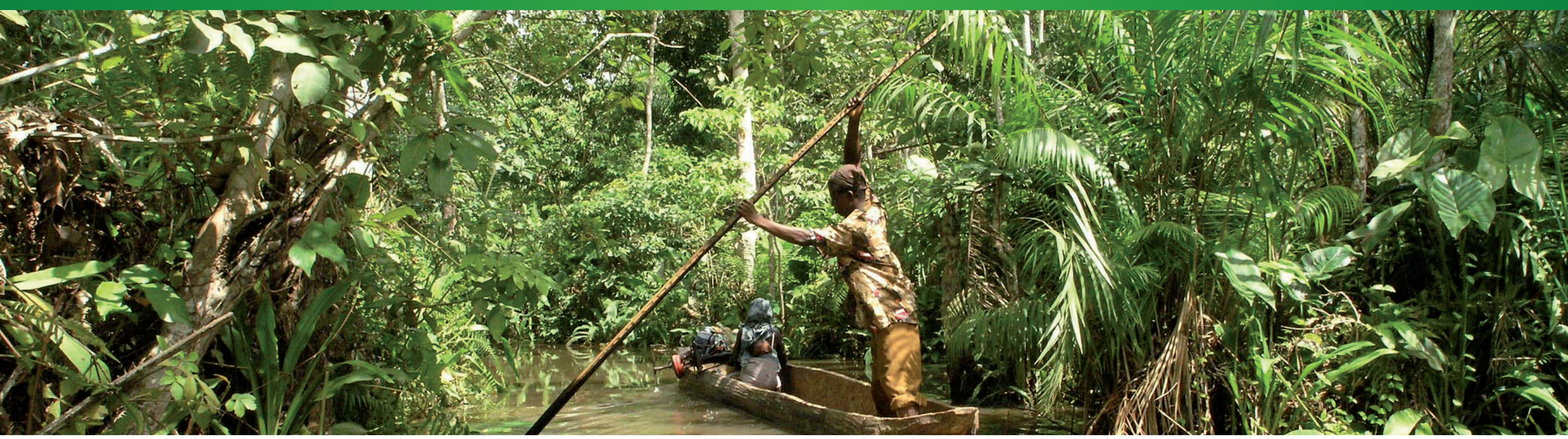
CLIMATE CHANGE VULNERABILITY OF AFRICAN FOREST PLANTATIONS AND THE ROLE OF PERMANENT SAMPLE PLOTS IN MONITORING, REPORTING AND VERIFICATION FOR REDD IN PLANTATION



AFRICAN FOREST FORUM WORKING PAPER SERIES

VOLUME 2 ISSUE 4, 2014

 African Forest Forum P.O. Box 30677 00100 Nairobi GPO KENYA Tel: +254 20 7224203 Fax: +254 20 722 4001 Website: www.afforum.org

Correct citation: Makundi, W.R. 2014. Climate change vulnerability of African forest plantations and the role of permanent sample plots in monitoring, reporting and verification for REDD+ in plantations. African Forest Forum, Working Paper Series, Vol. (2)4, 24 pp.

Cover photo: African Forest Forum

Climate change vulnerability of African forest plantations and the role of permanent sample plots in monitoring, reporting and verification for REDD+ in plantations

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Acronyms and abbreviations

CAR	Central African Republic
CO_2	Carbon Dioxide
COP	Conference of the Parties
DR Congo	Democratic Republic of Congo
FAO	Food and Agricultural Organization of the United Nations
FRA	Forest Resource Assessment
GCM	Global Circulation Model
GHGs	Greenhouse Gases
ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
MRV	Monitoring, Reporting and Verification
NAMAs	Nationally Appropriate Mitigations Activities
ppm	Parts per million (in volume).
ppp	Purchasing power parity
PSPs	Permanent Sample Plots
REDD+	Reduced Emissions from Deforestation and Degradation Plus
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

Given the potential impacts of climate change on the commercial forestry sector, and the fact that such impacts can already be detected in Africa, the development and implementation of adaptation policies, measures and strategies are crucial.

Although there is still uncertainty surrounding the magnitude and timing of climate change in the future, the negative impacts of this change are likely to be enormous. Thus, adaptation needs to occur in the immediate future. Processes need to be implemented now, as the time scales for these processes to take effect and be adopted are likely to be long in the case of plantation forestry.

In implementing adaptation measures, a 'no regrets' approach ought to take priority. The measures implemented under a no regrets approach will have benefits which are equal to or exceed their cost to society, and will be of benefit regardless of climate change. Other adaptive interventions will include:

- a change in forestry practices to using and developing more heat and drought resistant species and hybrids; the use of native species ought to be encouraged since exotic species tend to negatively influence biodiversity; however, this should be balanced against aspects of productivity and brevity of rotation age, and thereby the undisputed economic advantage of plantations, which are main factors associated with the introduction of exotics;
- mixing species, to provide insurance against some impacts of climate change, with plantation forestry moving towards mixed cultures rather than the currently dominant monocultures;
- better matching of species to their optimal ecological range, that is, if the site is currently at the dry end of the species' range, that species should no longer be planted there;
- giving consideration to climate change predictions when planning the future of African countries' plantation forestry in terms of species and provenance selection, tending, management regimes, production, consumption and trade of forest products;
- the use of water harvesting methods to relieve water stress during the establishment stage in order to give seedlings and saplings a good start via irrigation. This intervention can be supplemented with the use of fertilizers and boosters in the early stages of the plantation establishment.

The study and assessment of the extent of vulnerability of African forest and tree plantations to climate change and monitoring the effectiveness of any mitigation and/or adaptation intervention requires a scientific method consistent with how plantations have been established and managed in the past. Such a method requires the use of a sampling framework that can produce the information necessary to feed the policy/management

process. For as long as forest plantations have been established, management has deployed the use of permanent sample plots (PSPs) as a key part of a monitoring framework.

A temporary sample plot provides a snapshot of the attribute of interest, while a permanent sample plot allows for re-measurement over time that provides a dynamic picture of the attribute. Management of forest plantations in Africa has only put in place a few permanent sample plots to provide data for growth modelling, planning silvicultural interventions and harvesting cycles. A review in South African and Kenyan plantations found that the existing PSPs are inadequate even for plantation management purposes, mostly due to resource constraints. It is estimated that there exists less than 40% of the required number of PSPs in various states of management and monitoring.

In the wake of mitigation programmes like Reduced Emissions from Deforestation and Degradation (REDD+), permanent sample plots will be required to provide the necessary data for carbon accounting. Introduction of REDD+ in plantations in Africa will require a significant expansion of the number and location of the PSPs in order to obtain estimates of the carbon-relevant plantation attributes including below- and aboveground carbon density, detritus, products and decomposition profiles. Using a Kenyan study as a benchmark, it was estimated that in order to allow African plantations to fully participate in the REDD+ program, it will require at least 3000 PSPs to provide adequate data for aboveground biomass carbon stock for wall-to-wall monitoring, reporting and verification.

It is recommended that each country with forest plantations establish a biometric department at the plantation management level that will be charged with the responsibility to establish an adequate number of PSPs, and to collect and transmit data to a central repository from which REDD+ stakeholders can have seamless access. A region or continent-wide network of these data centres and practitioners will reduce costs by cross sectional sharing of pertinent data.

CHAPTER 1 Introduction

BACKGROUND

The accumulation of greenhouse gases (GHG) in the earth's atmosphere is projected to lead to a rise in global temperatures and related effects on the hydrological cycle. In the past few decades, atmospheric concentration of carbon dioxide (CO_2) - the most important GHG - has been rising by about 2 parts per million (ppm) per year, that is about 0.5% per year, and in 2013, for the first time in millions of years, the atmospheric concentration exceeded the psychological milestone of 400 ppm as measured at Mauna Loa Observatory in Hawaii (Keeling, 2012). To appreciate the importance of this level, it must be emphasized that the measurement started at about 280 ppm before the industrial revolution, and by about 100 years ago, levels had risen to c. 300 ppm, and crossed 350 ppm in the late 1980's. The last time concentrations of CO_2 were as high as 400 ppm was between 3 and 5 million years ago, when the world was much warmer, long before humans appeared on earth (Keeling, 2012 *op. cit.*).

The rise in the atmospheric concentration of greenhouse gases (GHG) and the resultant increase in earth's temperature and its impact on the hydrological cycle will have profound effects on the biosphere. A recent paper by scientists at Mauna Loa Observatory in Hawaii (Mora *et al.,* 2013) shows that by 2047, the temperature of most places on earth will have risen beyond its historical range. In other words, for a given geographical location thereafter, the coldest year in the future will be warmer than the hottest year in the past.

The generally accepted impacts of global climate change are now being observed in all facets of life on earth, in some cases with scientific evidence and in others with anecdotal information. The Intergovernmental Panel on Climate Change (IPCC) has firmly pronounced that Climate Change is affecting rainfall patterns, water availability and periodicity of precipitation, thawing of ice and glaciers, sea level rise, increasing droughts and bushfire frequency, intensity and frequency of extreme weather events, increasingly impacting on human and animal health, agriculture and land productivity, vegetation cover and biodiversity. In general, climate change impacts the environment in which humans live, thus affecting the livelihoods of many and incomes of nations (IPCC, 2013).

The interaction between forests and global climate change is intimate and extensive. Forests form the largest terrestrial ecosystem that significantly impacts the global climate while at the same time being affected by a changing climate in many significant processes. Forests are directly affected by the rise in atmospheric CO_2, the rise in ambient temperature, droughts and incline in precipitation. Forests also play a key role in adaptation to climate change, for example, by increasing the resilience of rural communities while they support species to adapt to changing climate patterns and sudden climate events by providing refuge and migration corridors. Also, they indirectly support economies to adapt to climate change by reducing the costs of climate-related negative impacts. Forest ecosystems also provide goods and services during extreme events (droughts, floods and heat waves) and are key assets for reducing vulnerability to the effects of climate change.

Forests have a considerable potential to sequester carbon through afforestation, reforestation, forest restoration and via changes in forest management practices. Other mitigation options in the forest sector include reducing emissions from deforestation and degradation, as well as more efficient use of biomass and substitution of fossil fuels or fossil-derived products for forest products. The scope of these activities is embraced by the various agreements by United Nation members/parties to the Rio Climate Change Convention (UNFCCC, 1992; UNFCCC, 1997; UNFCCC, 2012a).

Forest ecosystems will therefore be affected by climate change in both negative and positive ways. All five major forest ecosystems in Africa - Forests, Woodlands, Sahel, Mangroves and Plantations - will be affected in ways that are consistent with the site, qualities and constituents of the specific ecosystem. To examine the negative impacts to which human beings and communities have to prepare for and find ways to adapt to requires the identification of the biophysical and socio-economic vulnerabilities of the specific ecosystem to climate change. This study presents a general view of the vulnerability of one such ecosystem - African forest plantations. In addition, for the purpose of monitoring the impacts of climate change on plantations as well as involvement of plantations in GHG mitigation efforts, the study also examines the status of permanent sample plots (PSPs) and their adequacy for supporting the role of plantations in mitigation. It also identifies gaps and proposes solutions to rectify the situation as warranted.

OBJECTIVES

The main purpose of the study is to review available information on climate change vulnerability of forest plantations in Africa, specifically that of the biophysical systems such as soils, water, biological resources; and the socio-economic vulnerability of plantations and their stakeholders including human health, livelihoods, products, trade and development.

The second objective of the study is to examine monitoring, reporting and verification (MRV) issues, specifically that of plantation PSPs necessary to provide information to address the vulnerabilities, mitigation and adaptation in the specific ecosystem. This will involve assessment of data and information on PSPs, evaluation of the current status and potential of such plots to be a source of data for studying the impacts of climate change on plantations, and assessing the usefulness of the permanent sample plots in the REDD+ requirements in the event this programme is extended to cover forest plantations. The study also examines the need for long-term support of some key PSPs and proposes institutional arrangements for sustainable management of the PSPs for monitoring forest and tree resources and factors affecting plantations that may be affected by climatic change.

CHAPTER 2 Climate change vulnerability of forest plantations

Africa has a sizeable area under forest plantations (although still small compared to other continents), now estimated to approach 16 million ha, which is c. 4 % of the total forest area on the continent, and growing at about 276,000 ha per year (FAO, 2010), which is more than twice the planting pace in the 1990's. As shown in table 1, almost all African countries have a small plantation area, with Sudan and South Africa accounting for about half of the plantations on the continent. Sudan has more than 6 million ha classified by FAO as plantations which is almost four times the size of those in South Africa. Though these two counties have the largest plantation area in Africa, it should be pointed out that in the last two decades they have not expanded their forest estate significantly. It is also important to point out that the area presented by the Forest Resource Assessment (FRA) as plantations in Sudan include managed but natural forest areas under *Acacia senegal* (gum Arabic).

The African forest plantations are scattered across the continent's numerous agro-ecological zones. Because of this, their biophysiological vulnerability will be commensurate to the respective impacts projected for the area in question. Forest plantations are as vulnerable to climate change as other forest ecosystems, but the extent of positive or negative impacts can be moderated by management practices to which they are subjected as well as by the limited number of species involved compared to other major natural ecosystems.

Climate change is projected to result in increased temperatures and a reduction in rainfall in many parts of Africa (IPCC, 2007). Even in cases where rainfall will be unchanged or predicted to increase, the intensity will be heightened. The impact of such changes may affect forest plantations by changing their growth characteristics (decreased or increased growth rates), survival rates of trees and the structure of the ecosystem caused by influences on the botanical and zoological composition. Consequent to these ecosystem responses, plantations may either have increased or decreased energy and biomass contents which in turn may influence forest fire incidents and insect infestation, both of which will affect biodiversity. Obviously, forest plantations already have reduced biodiversity and as such climate change may not negatively impact this characteristic as much as in more biodiversity-rich natural ecosystems. A warmer climate may also result in more invasive and new species that may increase management and protection costs in existing forest plantations.

Table 1. Trends in extent of planted forests in 1990-2010. Source: FAO, 2010

Country/ area	Area of planted forest (1 000 ha)				Annual change rate					
	1990	2000	2005	2010	1990-2000		2000-2005		2005-2010	
					1 000 ha/yr	%	1 000 ha/yr	%	1 000 ha/yr	%
Angola	140	134	131	128	-1	-0.44	-1	-0.45	-1	-0.46
Botswana	0	0	0	0	0	-	0	-	0	-
Comoros	2	2	1	1	0	0	n.s.	-12.94	0	0
Djibouti	0	0	0	0	0	-	0	-	0	-
Eritrea	10	21	28	34	1	7.75	1	5.67	1	3.86
Ethiopia	491	491	491	511	0	0	0	0	4	0.80
Kenya	238	212	202	197	-3	-1.15	-2	-0.96	-1	-0.50
Lesotho	6	8	9	10	n.s.	3.17	n.s.	2.55	n.s.	2.26
Madagascar	231	272	290	415	4	1.65	4	1.29	25	7.43
Malawi	132	197	285	365	7	4.09	18	7.67	16	5.07
Mauritius	15	15	15	15	n.s.	-0.07	n.s.	-0.41	n.s.	0.27
Mayotte	n.s.	n.s.	1	1	n.s.	4.89	n.s.	11.06	n.s.	7.15
Mozambique	38	38	24	62	0	0	-3	-8.78	8	20.90
Namibia	0	0	n.s.	n.s.	0	-	n.s.	-	n.s.	34.76
Réunion	5	5	5	5	0	0	0	0	0	0
Seychelles	5	5	5	5	0	0	0	0	0	0
Somalia	3	3	3	3	0	0	0	0	0	0
South Africa	1626	1724	1750	1763	10	0.59	5	0.30	3	0.15
Swaziland	160	150	145	140	-1	-0.64	-1	-0.68	-1	-0.70
Uganda	34	32	31	51	n.s.	-0.60	n.s.	-0.63	4	10.47
Tanzania	150	200	230	240	5	2.92	6	2.83	2	0.85
Zambia	60	60	60	62	0	0	0	0	n.s.	0.66
Zimbabwe	154	120	108	108	-3	-2.46	-2	-2.09	0	0
E/S Africa	**3500**	**3689**	**3814**	**4116**	**19**		**25**		**60**	
Algeria	333	345	370	404	1	0.35	5	1.41	7	1.77
Egypt	44	59	67	70	2	2.98	2	2.58	1	0.88
Libya	217	217	217	217	0	0	0	0	0	0
Mauritania	5	13	17	21	1	10.03	1	5.51	1	4.32
Morocco	478	523	561	621	5	0.90	8	1.41	12	2.05
Sudan	5424	5639	5854	6068	22	0.39	43	0.75	43	0.72
Tunisia	293	519	606	690	23	5.88	17	3.15	17	2.63
N Africa	**6794**	**7315**	**7692**	**8091**	**54**		**76**		**81**	
Benin	10	13	15	19	n.s.	2.66	n.s.	2.90	1	4.84
Burkina Faso	7	58	78	109	5	24.23	4	6.26	6	6.84
Burundi	0	86	78	69	9	-	-2	-1.93	-2	-2.42
Cameroon	-	-	84	-	-	-	-	-	-	-
Cape Verde	58	82	84	85	2	3.58	n.s.	0.36	n.s.	0.36
CAR	2	2	2	2	0	0	0	0	0	0
Chad	11	14	15	17	n.s.	2.44	n.s.	1.39	n.s.	2.53
Congo	51	51	51	75	0	0	0	0	5	8.02
Côte d'Ivoire	154	261	337	337	11	5.42	15	5.24	0	0
DR Congo	56	57	57	59	n.s.	0.18	n.s.	0.18	n.s.	0.55
Gabon	30	30	30	30	0	0	0	0	0	0
Gambia	1	1	1	1	n.s.	0.74	0	0	0	0
Ghana	50	60	160	260	1	1.84	20	21.67	20	10.20
Guinea	60	72	82	93	1	1.84	2	2.64	2	2.55
Guinea-Bissau	n.s.	n.s.	1	1	n.s.	5.58	n.s.	7.85	n.s.	5.63

Country/ area	Area of planted forest (1 000 ha)				Annual change rate					
	1990	2000	2005	2010	1990-2000		2000-2005		2005-2010	
					1 000 ha/yr	%	1 000 ha/yr	%	1 000 ha/yr	%
Liberia	8	8	8	8	0	0	0	0	0	0
Mali	5	55	205	530	5	27.10	30	30.10	65	20.92
Niger	48	73	110	148	3	4.28	7	8.55	8	6.11
Nigeria	251	316	349	382	7	2.33	7	2.01	7	1.82
Rwanda	248	282	323	373	3	1.29	8	2.75	10	2.92
Senegal	205	306	407	464	10	4.09	20	5.87	11	2.66
Sierra Leone	7	8	11	15	n.s.	1.66	1	7.23	1	5.30
Togo	24	34	38	42	1	3.54	1	2.25	1	2.02
W/C Africa	**1286**	**1869**	**2526**	**3119**	**58**		**113**		**135**	
Africa	**11 580**	**12 873**	**14 032**	**15 326**	**131**		**214**		**276**	

Climate change will, in all likelihood, also significantly influence the economic and social systems through the influence it will have on managed agricultural and forest systems, as well as on natural ecosystems. Such influences may include increased conflicts over water resources, changed trading patterns, shortages of necessary consumer goods, influences on employment rates and opportunities, prevalence of certain diseases, etc.

In this section, a review of the extent of the biophysical and socio-economic vulnerabilities of African forest plantations will be reviewed and the actions to minimize the negative impacts to the ecosystem and to dependent socio-economic systems are explored.

BIOPHYSICAL VULNERABILITY

As mentioned in the previous section, the current atmospheric CO_2 level is 400 ppm, which is higher than it has been at any time in the past 3-5 million years. The consequence of the accumulating GHGs is projected to increase global temperature by, conservatively estimated, c. 2.0 - 3.5º C by the time the CO_2 level reaches double of its pre-industrial level, and further assuming that serious mitigation policies are pursued by the world community (UNFCCC, 2012a *op. cit.*). Other studies using more robust scenarios have predicted steeper rises in temperatures, as high as 2 - 6º C, a level that would lead to catastrophic events with extreme outcomes on plant growth and humans (Mora *et al.,* 2013, *op. cit.*). However, in the global negotiations, and specifically the last COP 18 in Doha, in its Decision 1/CP.18 consistent with previous decisions 1/CP.13, 1/CP.16, 1/CP.17 and 2/CP.17, it was decided that the Parties will urgently work towards a deep reduction in global greenhouse gas emissions required to hold the ***increase in global average temperature below 2° C above the pre-industrial levels*** and to attain a global peaking of global GHG emissions as soon as possible. This is consistent with what current science predict and as documented in the Fourth Assessment Report of the IPCC, reaffirming the consensus that the time frame for peaking will be longer in developing countries (UNFCCC, 2012b) since they still must develop their economies in order to alleviate the poverty and underdevelopment that their people are currently living under.

It has been convincingly shown that higher average temperatures will lead to changes in precipitation and atmospheric circulation, the magnitudes of which are currently hard to predict with acceptable accuracy, but with likely disruption of life in the biosphere as we know it (Harmeling, 2010). For example, the same study estimated that during the two decades since 1990 more than 650 000 people worldwide died from extreme weather events, and losses of more than US$ 2.1 trillion (ppp) occurred globally. It is noteworthy that most studies show the asymmetrical vulnerability between developing and industrialized nations, with the poor African countries being the most vulnerable to extreme events arising from global climate change, mostly due to their inherent low resilience and capacity to adapt to such change.

The vulnerability of, and impacts on, African forest plantations and associated socio-economic impacts discussed in this section assumes climate change arising from "doubling of atmospheric concentration of CO_2" from pre-industrial levels.

Plant functioning and climate change

An increase in the atmospheric concentration of CO_2 has effects on net photosynthesis, respiration, plant development, tissue chemistry and plant water use and therefore affecting plant growth rates (Field *et al.,* 1992). The increase in whole-plant production which is achieved under elevated CO_2, normally referred to as CO_2 fertilization, is less than the increase in the associated photosynthesis (Fairbanks and Scholes, 1999).

The amount of growth stimulation that occurs depends on the ability of the plants to use the extra carbohydrates productively, a process that is mostly a function of nutrient and water availability and night temperatures. It has been shown that under field conditions CO_2 fertilization can lead to a growth rate increase of about 10-20% (de Lucia *et al.*, 1999), although much higher rates can be achieved in the laboratory (Mooney *et al.,* 1999).

Crop physiology literature shows that along with an increase in biomass production, there are many other physiological changes in a plant grown at elevated CO_2 levels. The photosynthetic apparatus generally partly acclimatises to the surplus carbon assimilation by reduced enzyme activity per unit leaf area, reduced quantum efficiency or reduced leaf area (Idso, 1999). The allocation of photosynthates shifts in favour of the below-ground organs (roots). This is interpreted as a control mechanism to bring the plant nutrient supply back into balance with the enhanced carbon supply by increasing the nutrient and water intake capacity. The higher CO_2 concentration means that the stomatal conductance can be lower, while still permitting an adequate CO_2 flux to the mesophyll. This and the reduction in leaf size in response to higher ambient temperature have the benefit of reducing plant water loss, and thus increasing water use efficiency. Nutrient use efficiency (the dry matter produced per unit of nutrient assimilated) also increases, due to a decrease in tissue nutrient concentration.

It is apparently clear that integrated data over the whole season are necessary to evaluate the complete effect of increased CO_2 concentration on plant growth. To obtain the full impact of fertilization to plant growth, other factors such as climatic change induced temperature rise and changes in precipitation will need to be considered. Impact of CO_2 fertilization on forest plantations will need to be assessed given data on the parameters discussed above.

Impacts of temperature and precipitation change on plantations

Projections of climate change given various scenarios of GHG concentrations in the atmosphere are conducted by using Global Circulation Models (GCMs). Different GCMs have simulated climatic changes and showed regional impacts on temperature and precipitation. Outputs from the Genesis, CSM, and HADCM2 models used for assessing vulnerability of ecosystems in Southern Africa predict a generally increased aridity of the region with average temperature rise of 2.5 to 3.5º C combined with reduced rainfall in the next 100 years (Fairbanks and Scholes, 1999 *op. cit.*). The predictions referred to here come from the UK Meteorological Office Model Hardley Centre Unified Model 2 “without sulphates” which is considered to be more reliable than most GCMs.

The predicted greater incidence of drought is relevant to the risks associated with forest and non-forest tree plantations. General increases in aridity, due to lower rainfall and higher air temperatures, will affect the optimal growth ranges for the region’s primary tree species, both indigenous and already introduced exotics, and impact the marginal costs associated with planting in sub-optimal areas. In the absence of additional fire protection interventions, drying and higher temperatures may increase the frequency and intensity of forest fires including the area of plantations lost to fires.

Some studies in Southern Africa have confirmed the predictions of the GCM simulations. For example, the initial study by Warburton and Schulze (2006) which analysed a series of trends in temperature and rainfall parameters over the period 1950–2000 in South Africa, found that in almost every analysis two clear statistically significant clusters of warming over this period emerge, viz. over the Western Cape and around the Midlands of KwaZulu-Natal and its coast. The clusters show up in the analyses of annual means of both minimum and maximum temperatures, of cold spells, as well as of heat units.

Another distinct conclusion that can be drawn is the warming over the interior when analysing frost occurrences, with the Free State and Northern Cape provinces of South Africa standing out in this regard. There appears to be a shift towards an earlier ending of the frost season, and a shorter frost season with fewer frost occurrences. Changes in precipitation patterns were also identified. The impact of these projected changes in key climatic variables like temperature, precipitation and CO_2 fertilization were mapped into the plantation forestry using sensitivity analysis and the following results and conclusions on the biophysical vulnerability of plantations in South Africa were obtained (*Box 1*):

Box 1. Results of climate change sensitivity analyses in Southern Africa on different plantation tree species

Given the current distribution of species in various suitability classes shown in Table 2 below, the impact of climate change will produce a new distribution accordingly. The Fairbanks and Scholes (1999) study came up with the following conclusions on vulnerability of forest plantations to increased aridity and reduced precipitation predicted by GCMs:

For *Acacia mearnsii*, the largest climatically optimum area under present conditions occurs in KwaZulu-Natal. As temperature increases and rainfall decreases, the area which is climatically optimal in KwaZulu-Natal decreases significantly, with only an expansion in suitable area occurring when both temperature and rainfall increase. The same pattern, although with greater fluctuations, is evident in the Eastern Cape. In Mpumalanga province, however, the climatically optimum area for *A. mearnsii* increases when the temperature is increased by 1°C and 2°C, possibly due to decreased occurrences of frost. A decrease in the climatically optimum area would occur when temperature is increased and rainfall is decreased simultaneously, but a substantial increase in the climatically optimum area is projected to occur with both an increase in temperature and rainfall.

The climatically optimal area for *Eucalyptus* spp. in KwaZulu-Natal again decreases markedly with increasing temperatures, as well as with increased temperatures combined with decreased rainfall. The climatically optimum areas within the Eastern Cape are slightly less sensitive to increases in temperature in comparison to areas in KwaZulu-Natal; however, they are relatively more susceptible to decreasing rainfall. If an increase in rainfall combined with an increase in temperature were to occur, a larger area in the Eastern Cape would become climatically more optimal for the growth of eucalypts in comparison with the area under the present climate.

In Mpumalanga, the area which is climatically optimal for the growth of eucalypts increases slightly with a 1°C increase in temperature, and remains relatively stable for a 2°C increase in temperature when compared with the area under present climatic conditions. An increase in temperature of 2°C together with an increase in rainfall of 10% would, however, result in a far larger proportion of Mpumalanga meeting the climatic requirements for optimum growth of eucalypts.

In the case of *Eucalyptus* species/hybrids, *E. nitens* is highly sensitive to increases in temperature while the Eucalyptus hybrid evaluated, viz. Eucalyptus GxU, is more robust to changes in temperature. All the *Eucalyptus* species and/or hybrids are highly sensitive to changes in rainfall with respect to their climatic optimum growth areas. With regard to changes in actual areas suitable for eucalypts, KwaZulu-Natal is vulnerable should increases in temperature occur, while Mpumalanga and the Eastern Cape are more robust to increases in temperature.

Overall, the *Pinus* species and/or hybrids are relatively robust to potentially increasing temperatures and changing rainfall regimes. In relative terms, *Pinus* species were found to be more sensitive to increasing temperatures and decreasing rainfall than the *Pinus* hybrid which was considered, viz. *Pinus* ExC, which appears relatively robust to climate change. The climatically optimum areas within KwaZulu-Natal are likely to decrease with increasing temperatures, while actual areas which are climatically optimal for *Pinus* species/ hybrids in the Eastern Cape and Mpumalanga could expand under conditions of increasing temperatures.

Source: Fairbanks and Scholes, 1999.

This assessment can be extrapolated to forest areas of similar land profile in Africa in order to understand the vulnerabilities facing each plantation species on a given site. In this specific study, the following overall assessment of the sensitivity of plantation forestry to climate change emerged:

- the climatic variable to which forest species is most sensitive is rainfall;
- the hybrids of both eucalypts and pines are relatively more robust than commonly grown species like *Acacia mearnsii* to potential increases in temperature (in particular) and, to a certain degree, to decreases in rainfall;
- areas currently under plantations where the present climate is only moderately suitable will, under conditions of increasing temperature and decreasing rainfall, most likely become high risk areas; and thus species with large proportional areas at present already being planted in only moderately suitable climates are highly vulnerable to climate change (Table 2); this is also generally the case in many plantations in lower site class zones such as the Sahelian semi-arid areas or the vast miombo woodlands and savannas of eastern and southern Africa;
- on a provincial basis the climatically optimal areas for plantation forestry within KwaZulu-Natal are likely to decrease with climate change, while results indicate that areas in the Eastern Cape and Mpumalanga, in South Africa, may offer opportunities for expansion with increasing temperature; this is also applicable to colder areas in highlands where

trees are negatively affected by frost and it may also speed up the rate of growth by the lengthening of the warm season; and,

- of the three genera included in this study, i.e. *Acacia*, *Eucalyptus* and *Pinus* spp., the pines were found to be relatively more robust to climate change than the other two, followed by *Eucalyptus* (Fairbanks and Scholes, 1999 op. cit.).

Table 2. Areas planted with *Acacia, Eucalyptus* and *Pinus* species/hybrid expressed as % of climatic suitability classes in South Africa.

Optimum suitability	Percentage of current planted areas		
	A. mearnsii	*Eucalyptus* species/hybrids	*Pinus* species/hybrids
Optimum	36.9	82.5	75.5
Moderate risk	43.0	4.4	17.0
High risk	18.7	6.8	1.5
Climatically unsuitable	1.4	6.3	6.0
Totals	100	100	100
Source: Fairbanks and Scholes, 1999 *op. cit*.			

In concluding the discussion on biophysical vulnerability, it is observed that, for African plantations in general, rising temperatures will stimulate growth in areas that are currently cooler than the growth optimum for the species concerned, and reduce it where trees are already growing in areas warmer than this optimum. Higher rainfall will normally increase biomass production, and lower will decrease it.

Increased atmospheric CO_2 concentration will marginally stimulate tree production, with net increased productivity redistributed, with most of it being stored below ground as a mechanism to respond to an elevated demand for water and nutrients for increased photosynthesis. Nutrients and water are the main constraints in the tree's ability to take advantage of increased CO_2 levels.

A warming climate will encourage movement of pests and diseases from tropical/warmer ecosystems into currently cooler regions of the continent. This is likely to increase the vulnerability of plantations in such areas to new diseases and pests. Other vulnerabilities of climate change to plantations arising from the rise in average, minimum and maximum temperature, and the decline in rainfall, include:

- droughts will lead to increased amounts of dry wood in plantations and thereby more fuel and consequent increased risks of fire;
- higher temperatures lead to higher temperature differentials that will feed winds, which, when coupled with flash rains, may lead to landslides, gully erosion and tree wind-falls;
- increased mortality from insect infestation caused by drier and abundant dead biomass;
- species migrations caused by climate change may lead to introduction of new weeds, insect/mammal/bird pests and fungal/microorganism diseases in some plantations.

SOCIO-ECONOMIC VULNERABILITY

The potentially positive effects of increased minimum temperature that reduce the number of trees killed by frosts and the fertilizing effect of higher atmospheric CO_2 are important ameliorating influences in currently cool climates. Temperature, atmospheric CO_2 and rainfall predictions are all critical in forecasting changes in plantation tree yield and its socio-economic impacts. The following are some brief assumptions on possible socio-economic impacts on plantation forestry:

- reduction of rainfall will lead to a need for introduction and wider use of drought resistant or less water dependent species, some of which may have desirable economic characteristics such as timber quality, fast growth and favourable economics. However, when considered across large landscapes, significant decline of available water would normally reduce the scope of tree species, thus also reducing the choice of plantation species suitable for and adapted to the new climates of the continent. This will be more pronounced for countries that have medium and low precipitation;
- decline in plantation productivity, for whatever reason, will normally lead to reduction in income for the owner and reduced employment. This, in turn, may negatively affect plantation dependent communities in rural areas where gainful employment is already scarce, leading to a higher rural-urban migration, especially of the youth;
- the predicted shifting of optimum tree planting areas as described above (Box 1) may impact profitability of plantation forestry since there are many fixed capital investments such as roads, sawmills, pulp and paper mills, etc., the geographical location of which are based on current optimum conditions and considerations;
- decline in plantation output can lead to rising prices of forest products unless shortfalls are obtained from expanded harvesting in natural forests and/or from increased import, options that has adverse effects both on the environment and on trade balance and foreign reserves;

- the climate change-driven water stress in marginal areas may lead to increased land use conflicts between plantation investors and farmers/pastoralists, all fighting for the use of scarce land with adequate water supply.

Due to the vastness of the predominant African ecological zones, it seems unlikely that there will be a continent-wide decline in areas suitable for plantations. The most likely scenario is a shift of areas within locales and within countries, as well as a shift to more climate change resilient species, but it is unlikely that there would be a decline in existing plantation area on the continent as a result of by climate change. However, potential plantation output is likely to decline due to climate-driven water stress that will intensify competition for land between production of food and fibre, with the former, for obvious reasons, being preferred over the latter.

RECOMMENDATIONS

Given the potential impacts of climate change on the commercial forestry sector, and the fact that changes in climate can already be detected in Africa, the development and implementation of adaptation policies, measures and strategies are crucial.

Although there is still uncertainty surrounding the magnitude and timing of climate change in the future, the negative impacts of it are likely to be enormous. Thus, adaptation measures need to be taken in the immediate future, as the time scales for such processes to take effect and be adopted are likely to be long in the case of plantation forestry.

In implementing adaptation measures, a ‘no regrets’ approach ought to take priority. The measures implemented under a no regrets approach will have benefits which are equal to or exceed their cost to society, and will be of benefit regardless of climate change. Other adaptive interventions will include:

- a change in forestry practices towards using and developing more heat and drought tolerant species and hybrids. The use of native species ought to be encouraged since exotic species tend to negatively influence biodiversity. However, this should be balanced against aspects of productivity and brevity of rotation age, and thereby the undisputed economic advantage of plantations, which are main factors associated with the introduction of exotics;
- mixing species, to provide insurance against some impacts of climate change, with plantation forestry moving towards mixed cultures rather than the currently dominant monocultures;
- better matching of species to their optimal ecological range, that is, if the site is currently at the dry end of the species’ range, that species should no longer be planted there;

- giving consideration to climate change predictions when planning the future of African countries' plantation forestry in terms of species and provenance selection, tending, management regimes, production, consumption and trade of forest products;
- the use of water harvesting methods to relieve water stress during the establishment stage in order to give seedlings and saplings a good start via irrigation. This intervention can be supplemented with the use of fertilizers and boosters in the early stages of the plantation establishment.

The study and assessment of the extent of vulnerability of African forest plantations to climate change as well as to monitor the effectiveness of any mitigation and/or adaptation interventions requires a scientific method consistent with how plantations have been established and managed in the past. Such a method requires the use of a sampling framework that can produce the information necessary to feed the policy/management process. For as long as forest plantations have been established, management has deployed the use of permanent sample plots (PSPs) as a key part of the sampling framework. The next section discusses the use of and extent of PSPs in monitoring climate change vulnerability in African forest plantations.

CHAPTER 3 Permanent Sample Plots

Sampling has long been an integral part of forest inventory. It is normally defined as the enumeration of growth and quality characteristics of forests, and of goods and services derived from it, of interest to forest stakeholders, such as forest owners, managers, concessionaires, etc. The goods and/or service of interest may include timber, biomass, carbon storage, recreational attributes, and wildlife, to mention but a few. These attributes constitute a population and a sample is usually a small unit that contains the attribute of interest which is used to provide the measurements that are necessary to estimate the extent of the attribute in the forest population, most commonly the average or expectation value of, say, merchantable timber, growth rate, carbon density, etc. A temporary sample plot provides a snapshot of the attribute of interest, while a permanent sample plot allows for re-measurement over time that provides a dynamic picture of the attribute.

PSPs have been a part of forest management for as long as forest inventory has been around (Menzies, 1994; Xu, 1992; Husch *et al.,* 1972; Streets, 1962; Beetson *et al.,* 1992; Picard *et al.*, 2010; DWA&F, 2002). For example, as far back as 1921, Finland completed the first national forest inventory in the world and has gone on to establish a network of more than 3500 PSPs in their forest estate (Priyard *et al.,* 2005). Some countries have a large number of PSPs, e.g. China has more than 200,000 sample plots (Xu, 1992 *op. cit.*). African countries have much fewer PSPs but they do exist in varying degrees in many forested countries. For example, in 2005 the South Africa Department of Water Affairs and Forestry listed 20 well documented PSPs that were established, beginning 1987, in the country's mixed-evergreen natural forests and are re-measured every 10 years (DWA&F, 2005).

Similarly, PSPs in forest plantations date as far back as plantation management. For example, there were at least 221 PSPs in Burmese teak plantations in India by 1937 (Laurie and Ram, 1939). In 1998, a South African forestry company, Komatiland Forests Limited (KFL), initiated a PSP programme for the purpose of studying the productivity of plantations. By 2001, the number of PSPs had grown to more than 120, covering the major plantation species in the country, i.e. *Pinus* and *Eucalyptus spp.* (Maplanka, 2005).

The appropriate number of PSPs in a given forest ecosystem and/or management area is determined by statistical criteria derived from the variation in the target variable and desired precision level, but also paying some attention to resources available for undertaking this exercise. The plots are usually well laid out and marked in the forest and on maps, placed in such a way as to minimize the chance of their removal during the lifetime of the forest.

The use of permanent sample plots in plantation forestry is of immediate significance with respect to assessing vulnerability and adaptation to climate change. *Box 2* below presents various reasons as succinctly described by Vanclay *et al.,* 1995.

Box 2: Importance of PSP in assessing vulnerability of forest plantations

Plantations represent a considerable investment of time and resources, and efficient management is necessary to recoup this investment. The potential value of effectively managed plantations offers many options and incentives for silvicultural interventions. Computer simulation models and information systems can help to explore these options and their implications, but all these depend upon suitable data.

The intensive management and financial risks characteristic of plantations demand reliable data and detailed information systems. Fortunately, it is comparatively easy to gather data in plantations. Access is usually good, and existing records may provide a suitable basis for stratification. Plantations are normally rather uniform, so relatively few and small plots can be used because the adequate number of sample plots depends on the variance of the attribute for which information is sought, the rule being that the higher the variance the bigger the number of sample plots required to meet the precision accuracy and reliability of estimates derived from sampling. The cost is one factor to consider, usually when determining the precision level desired and possibly the location of plots. Since the unit cost of data collection in plantations is comparatively low and the potential benefits are considerable, it should be possible to justify a comprehensive database.

Plantation managers and planners need to know the optimal silvicultural regimes including initial spacing, intensity and timing of thinnings, rotation length and regeneration method. They also need to know the sensitivity of these operations to site quality and socio-economic assumptions. They must also forecast harvests from existing plantations, and plan the steady and sustained flow of timber (and other products and services) into the market place.

Source: J.K. Vanclay, J. Skovsgaard & C. Pilegaard Hanse, 1995

The same reasons for the need for PSPs to enable effective and efficient plantation management apply for Monitoring, Reporting and Verification (MRV) in plantations for REDD+. These PSPs would be much more needed simply because of the additional dimension of environmental integrity regarding carbon emission reduction, or sequestration, that involves additional transfer of finances, whether publicly funded or market driven or a combination of the two. The introduction of REDD+ in African plantations will necessitate collection of additional data from sample plots, including but not limited to growth rates of above and below ground biomass and detritus, carbon stored in wood products and its eventual emission profile, accumulation of soil carbon, disturbances, decomposition rates as well as offsite translocation of biomass to other pools such as water bodies.

As described in Vanclay *et al.*, 1995 *op. cit.*, there are some key issues that must be taken into account when establishing PSPs. The plots should sample a wide range of site and stand conditions to provide for valid inferences on the attributes of interest. PSPs may be classified as experimental plots or passive monitoring plots. Too often PSP systems comprise mainly passive monitoring plots in "typical" stands, and this severely restricts the ability of resulting models to provide inferences on optimal silviculture. It should also be noted that for the purposes of REDD+, the PSPs should be able to provide baseline data regarding the actual status of the plantation in the absence of deforestation.

To find out what happens when you disturb a system, you have to actually disturb it, not just passively observe it (Box, 1966). Hence, a PSP system for plantations should include experimental plots which are manipulated to provide data on a wide range of stand density, a range of thinning regimes (heavy/ light, early/late, above/below), and data from stands which have been allowed to develop beyond normal rotation age. Sample plots should be established in all geographical regions in which plantations have been established or are proposed.

Informed plantation management requires a good database, since the quality of information depends on the quality of data, growth models and other planning tools. There are several important questions concerning permanent plots: how many plots, where to put them, and how to manage them. Plot measurement procedures are also important.

The quality of data is paramount, so, if resources are limiting, it is better to have a few well managed plots (i.e. with regular, detailed and accurate measurements), than many inadequate ones. For carbon stock change purposes, it is critical that PSPs be optimally placed in order to sample the full data space, especially when resources limit the number of plots, since carbon stock determination is linked to compensation per tonne of carbon sequestered or per tonne of emissions avoided.

Issues and topics related to monitoring of forest ecosystems such as forest health, forest productivity, services other than wood, especially water and climate regulation through carbon sequestration and emission reduction, drive the need for effective management of permanent sample plots. Forest plantations have traditionally used PSPs for measuring yield, usually intended to obtain merchantable stem volume. Basically, there were three important parameters that were sought from the PSPs, viz. diameter increment, volume increment and stand structure dynamics.

Existing databases need to be evaluated in order to identify areas of weakness and to be able to plan remedial sampling schemes. Usually, two key relationships can provide information necessary to estimate site class and conditions represented by the database, viz. site index versus age and stocking versus tree size. However, it is important that these variables, especially site index, be reliably determined. Where there is doubt about the efficacy of site index estimates, it is prudent to stratify the database according to geography, soil/geology or yield level (total basal area or volume production).

Established PSP systems may sample a limited range of stand conditions, and clinal designs are an efficient way to supplement such data to provide a better basis for silvicultural measures (Alder, 1999). Such supplements will be necessary for obtaining adequate data for MRV of REDD+ in plantations.

STATUS AND POTENTIAL OF EXISTING PSPS FOR REDD+

In African forest plantations, there are too few PSPs used by mensuration departments for obtaining data for planning, silvicultural and management purposes. For example, as mentioned in section 2 above, by 2001 there was only c. 120 PSPs in *Pinus* and *Eucalyptus* plantations in South Africa, which is a very small number for a country boasting almost 1.8 million ha of plantations (Maplanka, 2005 *op. cit.).* It is expected that other countries have even smaller numbers of PSPs in their plantations but such data are not readily available.

Due to a special collaboration programme between Kenya and the University of Michigan in the United States, Kenya has assembled a database of existing and newly established PSPs in an effort to monitor landscape-wide carbon density in the country that would also serve as a good basis for effective participation in REDD+. There are 144 sample plots in Kenya’s 197 000 ha of forest plantations that have been used to provide data for estimating above ground carbon density, and for the 700 000 ha of natural forests there are 385 plots (Smalligan, 2011). Prior to this effort to obtain wall-to-wall carbon density data for Kenya’s land use sector, there were only 58 sample plots in plantations, a situation which is still assumed to have been better than many African countries except South Africa. Unfortunately, there are limited resources set aside for plantation forest management, which means that the frequency of re-measurements in existing sample plots might not be adequate to produce the data necessary for carbon accounting under the Kyoto Protocol or for use in the new mitigation regimes such as REDD+ or Nationally Appropriate Mitigations Activities (NAMAs).

More importantly, normal timber plantation management only needs data on growth rates and volume of merchantable timber, and seldom on parameters necessary for carbon accounting, such as wood density, carbon content of biomass, non-merchantable timber, belowground biomass, litter deposition, mortality rate, decomposition rates, product utilization and soil carbon. Thus, REDD+ or other mitigation programmes in plantations will have to use the existing permanent sample plots but also augment them in order to meet the increased data needs of these mitigation activities.

Even if the PSPs were adequate for yield measurements, it is unlikely that they would be adequate for the other parameters since adequate sample size is critically dependent on the variance of the intended variable and the desired precision of target parameters. The distribution of sample plots in a plantation for volume data is different from that of soil carbon data due to the intrinsic difference in their strata and complexity (Eswaran *et al.*, 1993).

In this study, the Kenyan biomass sampling study is used as a benchmark to estimate the number of sample plots necessary for the entire African plantation estate. In Kenyan plantations, the previously existing sample plots were 40 percent of those deemed adequate in the biomass study in question where each sample plot was taken to represent 5 000 ha of plantation (Smalligan, 2011 *op. cit.*). Assuming similar species diversity and comparable eco-floristic zones, and if this sampling intensity was to be undertaken for the 16 million ha of plantations in Africa, at least 3 000 sample plots would be needed for obtaining aboveground carbon stock. Once good estimates of aboveground carbon stocking are obtained, one can use allometric equations and expansion factors to obtain total vegetation carbon stock in the plantation.

For carbon accounting, it will be necessary to put in place some destructive sampling plots so that data can be obtained for the non-volumetric parameters. These destructive sampling plots may be few for plantations of the same species compared to multi-species plantations. Some of the generic data such as that of carbon content or wood density may be obtained from literature since there is no significant variation within species.

Non-timber plantations - e.g. wattle, rubber, palms, etc. - may not have PSPs equivalent to timber plantations due to the different management objectives. The management of the 680 000 ha of rubber plantations on the African continent will be more interested in yield of rubber than wood growth. Since these plantations are as vulnerable to disturbances as other tree plantations, and are as likely to be included in mitigation programmes like REDD+, it is imperative that PSPs are established for carbon stock monitoring, reporting and verification, including also biodiversity monitoring. Fires and other deforestation and degradation agents may destroy existing PSPs and as such will require to setting up remedial PSPs.

REQUIRED INSTITUTIONAL CHANGES

In order to satisfy the extensive data need required to monitor REDD+ programmes in plantations, each country needs a network of PSPs in different plantations. To reduce duplication of efforts a regional network of PSPs need to be developed and the requisite database shared by various stakeholders, including REDD+ project developers, validators, financiers, carbon buyers and the United Nations Framework Convention on Climate Change (UNFCCC) REDD+ secretariat. There is a need for integrating forest information over space and time that requires efficient strategies to supplement deficient databases in order to serve the broader objective of GHG mitigation.

Establishment of accessible national databases should form the backbone of a regional and/or continent-wide network of PSPs and landscape-wide information such as extent of changes in land-use and quality of various ecosystems. Monitoring changes in forest lands close to plantations will provide a basis for assessing extent of leakage associated with REDD+ plantation programmes and/or projects.

In order to achieve valid and steady results in the way PSP data are handled and managed, it is considered necessary to establish a national growth and yield network since REDD+ programmes/ projects will use national or regional baselines and the periodic monitoring of avoided emissions and carbon gain will be monitored from this network of PSPs.

It is therefore recommended that a national institution, or a dedicated office in an existing relevant institution, be established with mandate and resources to manage the network of PSPs and be the repository of all information collected from the sample plots. To facilitate this process, each plantation management unit should have a biometric department/section that manages and collects the data from the PSPs and forwards it to the national repository. Such an institution will also be charged with the responsibility to collect associated data, including biodiversity monitoring, product utilization, product useful lifetimes, etc., that are deemed necessary for monitoring all mitigation projects/programmes in the forestry sector. Plantations should only be a part of the focus of this carbon information centre or clearing house.

To enable the network of biometric departments in each plantation management unit, as well as the experts at the national/regional centre, it is imperative that responsible staff undergo necessary training in order to harmonize measurement processes and maintain a desired level of accuracy and consistency. Quality assurance programmes must be in place to ensure reliability of the data since it will be used for validation and accreditation of carbon benefits to various stakeholders.

CHAPTER 4. Conclusion and recommendations

Sampling is an integral part of forest inventory which in turn is critical to effective forest management. A temporary sample plot provides a snapshot of the attribute of interest, while a PSP allows for re-measurement over time, thereby providing a dynamic picture of the attribute. Management of forest plantations in Africa has put in place a few PSPs to provide data for growth modelling, planning silvicultural interventions and harvesting cycles. A review of PSPs in plantations in South Africa and Kenya found that these are inadequate, due to resource constraints, even for plantation management.

In the wake of mitigation programmes like REDD+, PSPs will be required to provide the necessary data for carbon accounting. Introduction of REDD+ in plantations in Africa will require a significant expansion of the number and location of PSPs in order to obtain estimates of carbon relevant plantation attributes such as below and aboveground carbon density, detritus, products and decomposition profiles. Using the Kenya study as a benchmark, it was estimated that to allow African plantations to fully participate in the REDD+ programme, it will require at least 3 000 PSPs to provide adequate data for aboveground biomass carbon stock. It is estimated that less than 40% of this currently exists in various states of management and monitoring.

It is recommended that each country with forest plantations establish a biometric department at the plantation management level that will be charged with the responsibility to establish adequate numbers of PSPs and collect and transmit data from these to a central repository to which REDD+ stakeholders can have seamless access. A region or continent-wide network of these data centres and practitioners will reduce costs by cross sectional sharing of pertinent data.

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