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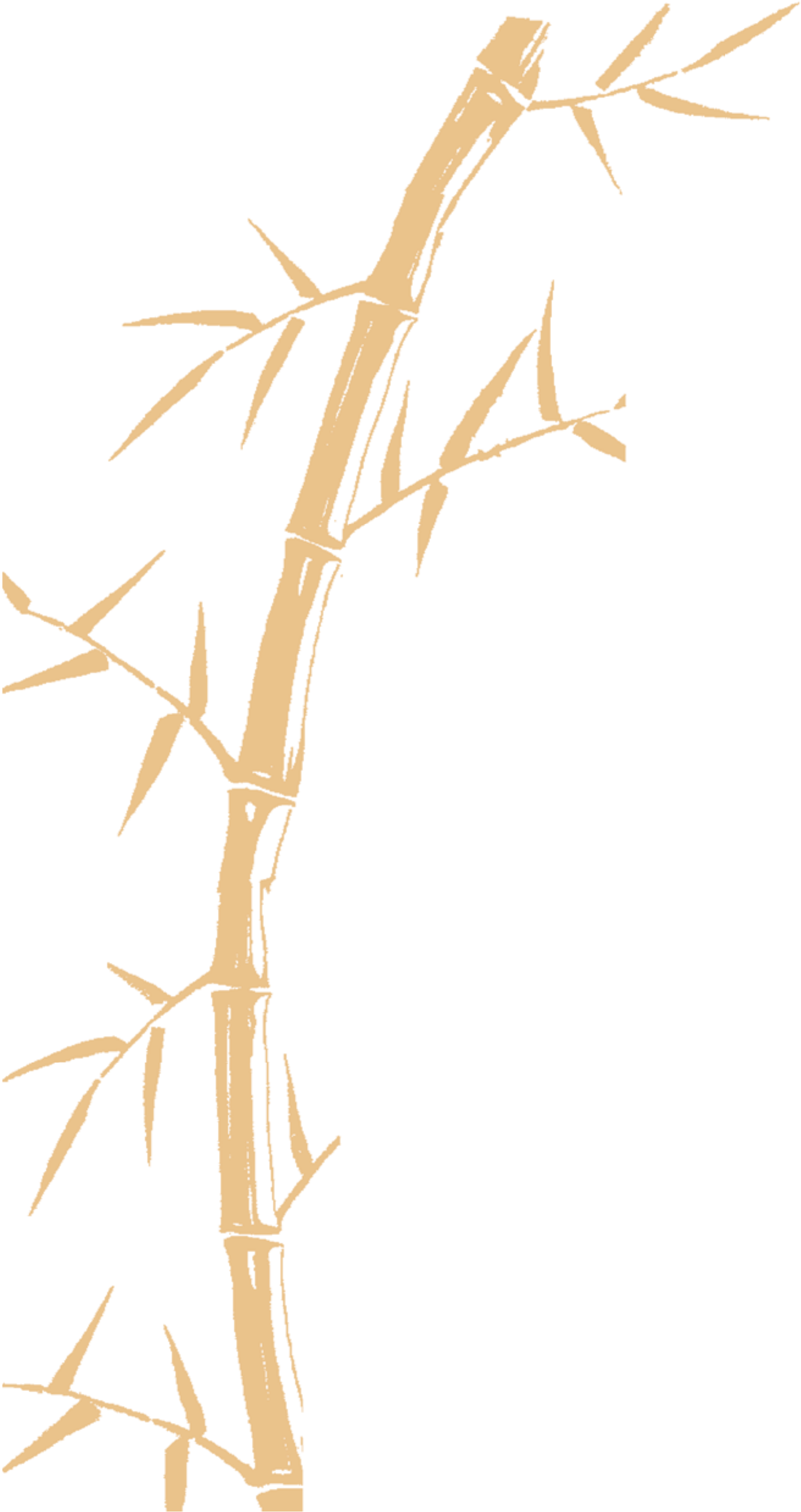
FORESTRY DEPARTMENT

THE POOR MAN'S CARBON SINK

BAMBOO IN CLIMATE CHANGE AND POVERTY ALLEVIATION



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THE POOR MAN’S CARBON SINK

BAMBOO IN CLIMATE CHANGE AND POVERTY ALLEVIATION

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All comments and suggestions are welcomed.

“The province named Tebeth was laid entirely waste at the time that Mangù-khan carried his arms into that country. To the distance of twenty days’ journey, you see numberless towns and castles in a state of ruin; and in consequence of the want of inhabitants, wild beasts, and especially tigers, have multiplied to such a degree that merchants and other travelers are exposed there to great danger during the night.

In this region, and particularly in the neighborhood of rivers, are found canes of the length of ten paces, three palms in circumference, and three palms also in the space between each knot or joint. Several of these, in their green state, the travelers tie together, and place them, when evening approaches, at a certain distance from their quarters, with a fire lighted around them, when, by the action of the heat, they burst with a tremendous explosion. The noise is so loud as to be heard at a distance of two miles, which has the effect of terrifying the wild beasts and making them fly from the neighborhood”.

Marco Polo, ca.1299

“Grazing and fire are two serious sources of injuries to bamboo forests. During the dry season, the stands are very vulnerable to fire, which spreads through the forest with its dense dry undergrowth. The culms explode with a sharp whip-crack, which is even more dramatic than the fire front”.

Walter Liese, 1985

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FOREWORD

Bamboo, best known by many as food for giant pandas, has been overlooked in the current climate change regime. Bamboos are missing from the Marrakech Accords definition of forests, as well as from IPCC Assessments and IPCC Guidelines for greenhouse gas inventories and reporting. Botanically not trees but grasses, and related to wheat, rye, barley, corn, and sugarcane, bamboos cannot, verbatim, form forests consisting of trees, as defined by the Kyoto Protocol. Nevertheless, with good reason they have been dubbed the "poor man's timber". The label conveys a near perfect match of bamboo to the goals of the Clean Development Mechanism in forestry, namely, poverty reduction and carbon sequestration. For more information on the subject please refer to Maxim Lobovikov, FAO; Lou Yiping, INBAR; Dieter Schoene, FAO retiree and Raya Widenoya, Tuffs University graduate.

Maxim Lobovikov
Forestry Department, FAO

ACRONYMS AND ABBREVIATIONS

AI	Countries listed in Annex I of the UNFCCC
A/R	Afforestation and Reforestation
AGB	Aboveground Biomass
AR4	Fourth Assessment Report of the IPCC
B/A-ratio	Belowground/ Aboveground Biomass Ratio for bamboo
BCEF	Biomass Conversion and Expansion Factor
BECS	Biomass Energy with Carbon Capture and Storage
BEF	Biomass Expansion Factor
C	Carbon
CDM	Clean Development Mechanism of the KP
CER	Certified Emission Reduction
COP	Conference of the Parties to the UNFCCC
CP	Commitment Period for achieving emission reductions
CRP	Crediting Period
DBH	Diameter at Breast Height
DEN	Apparent Green Density (bamboo cavity included in volume)
DNA	Designated National Authority
DOE	Designated Operational Entity
EB	Executive Board of the CDM
EU	European Union
FAO	United Nations Food and Agricultural Organization
GHG	Greenhouse Gas
GPG	Good Practice Guide (IPCC 2003 publication)
Gt	Gigatonne (10^9 t)
h/d-ratio	Ratio of tree height (cm) over DBH (cm)
INBAR	International Network for Bamboo and Rattan
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
LAI	Leaf Area Index
lCER	Longterm Certified Emission Reduction
MA	Marrakech Accords
Mt	Megatonne (10^6 t)
NAI	Non-Annex I countries, not listed in Annex I of the UNFCCC
NMVOC	Non-Methane Organic Volatile Compounds
PDD	Project Design Document for a CDM project
PoA	Programme of Activities uner CDM
REDD	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
tCER	Temporary Certified Emission Reduction
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

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EXECUTIVE SUMMARY

Bamboos are normally shaped like wood trees. Some species can reach up to 40 m in height and over 30 cm in diameter. Bamboos perform significant climate services and enhance rural livelihoods through a myriad of attractive products and services. The study advances arguments for considering bamboo stands as forests under UNFCCC, the Kyoto Protocol, in IPCC reports, and future agreements on climate change mitigation and adaptation.

Other bamboo characteristics complement trees qualities: broad distribution, short rotations, low capital and high labor intensity, attractive economic returns, persisting belowground carbon stores, high efficiency of conversion to commercial products, and relatively low investment risk. Bamboos appear particularly suitable to Small-Scale Afforestation/Reforestation Projects, Programmes of Activities, and Temporary Certified Emission Reductions under the CDM.

CDM has largely ignored the forest sector. Of approximately 1880 projects registered by November 2009, only eight are forestry projects. Bamboo afforestation/reforestation projects would skirt many of the stumbling blocks that affect tree plantations under the CDM. Bamboo projects could redress the unfortunate current state of the CDM, which, in spite of its lofty development goal, leaves behind many countries, that need development most.

Recently, the Executive Board of the Clean Development Mechanism has allowed bamboos in afforestation/reforestation projects in principle, delegating the final decision to individual countries. So far, this revision applies to the CDM only. So far only two countries have formally accepted bamboo in afforestation/reforestation projects.

Not considering bamboo stands as forests in a future regime of reducing emissions from deforestation in developing countries (REDD), would neglect significant carbon stores, highly effective carbon sinks, and proven pillars of rural livelihoods. Such a decision would also invite destruction of bamboo forests and cause emissions that are just as harmful as those from timber species.

Climate Change will not spare bamboo, necessitating management to adapt. However, short growing cycles, resilience, adaptability to temperatures extremes and species richness allow for hedging and flexibility. By reducing poverty, by providing remarkable socio-economic and environmental services, and serving as a substitute for timber trees, bamboos can help human societies adapt to climate change. Fast establishment and easy integration of bamboos into urban systems, croplands, agroforestry, and shifting cultivation may expand these services.

Ancillary beneficial effects of bamboo are not limited to only nurturing panda bears. Bamboos shelter other species, harbor virtual microcosms of biodiversity in hollow culms, reclaim degraded sites, provide shelter during tsunamis, floods, and earthquakes. On the other hand invasiveness of some bamboo species may harm the environment.

Bamboos may face their own specific hurdles in the CDM and REDD. Inventory methods, definitions, carbon measurement, and some parameters designed for timber trees are rarely applicable to bamboos, justifying a possible amendment to IPCC guidelines. By reviewing the available literature, this study obtaines some preliminary results and indicative parameters regarding carbon inventories in bamboo. Follow-up studies on suitability, economics, yield, vulnerability and carbon assessment would lower hurdles for bamboo A/R and REDD projects and strengthen bamboo's role as the poor man's carbon sink.

INTRODUCTION

This study sees bamboo as a bridge between climate change mitigation and poverty alleviation. Intergovernmental Panel on Climate Change (IPCC) promoted issues of climate change mitigation and adaptation. The Fourth Assessment Report (AR4) presented compelling evidence and sobering projections for the future climate change and its likely impacts (IPCC 2007b). The Clean Development Mechanism (CDM) of the Kyoto Protocol (KP) has explicit dual goals of assisting developing countries in achieving sustainable development, and industrialized countries in meeting their quantified emission limitations. It has spawned over 1880 registered projects by November.2009. These projects will reduce emissions by approximately three Gigatonnes (Gt) of CO_2 by 2012. The CDM has already produced more than three hundred million Certified Emission Reductions (CERs).

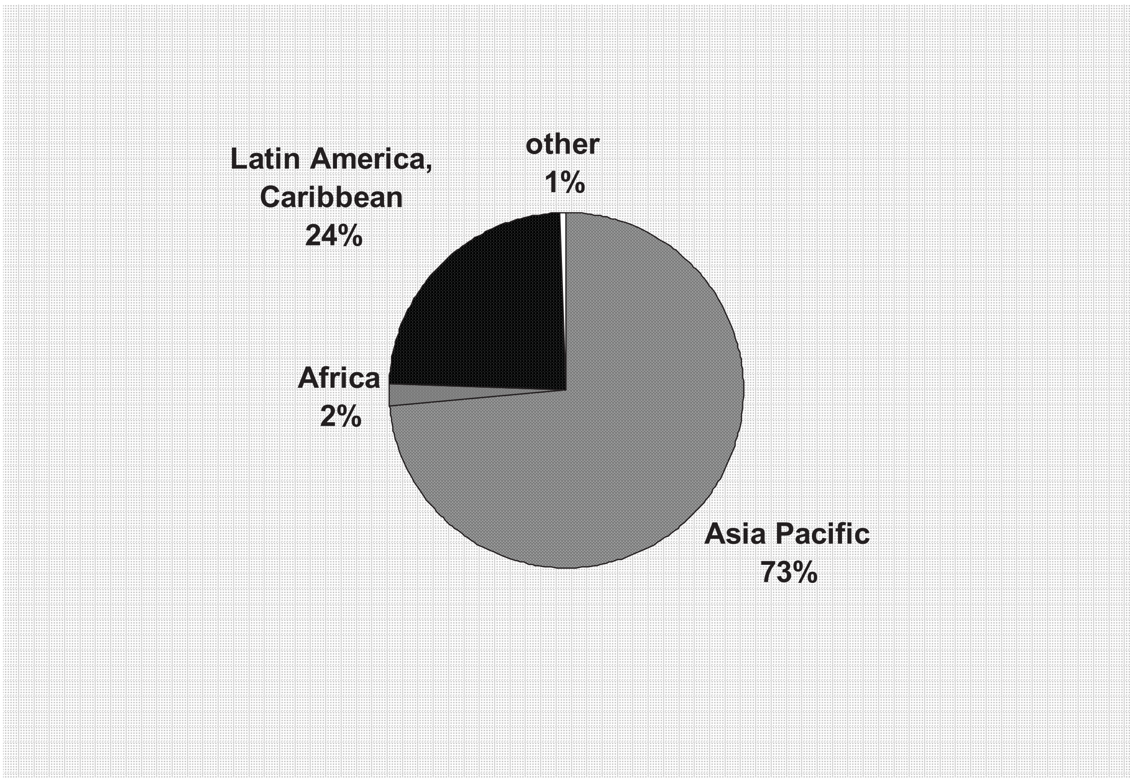
Table 1 illustrates an uneven spread of registered CDM projects. China hosts roughly one third of all projects. India, Brazil, Mexico, Malaysia, South Korea, Indonesia, Chile, Thailand and the Philippines together harbor about half of the CDM projects. Ten host countries share 87% of all projects. Africa, on the other hand, accounts for only 1.8% of the projects, Figure 1. South Africa hosts half of all 34 projects on the African continent. The CDM, despite its ambitious development goals, often leaves behind continents, countries and sectors, that need development most. Currently, only eight of all registered CDM projects are afforestation /reforestation (A/R) projects.

Table 1. The most frequent host CDM countries by November 2009

Country	*number of projects*	*% of all projects*
China	631	35
India	454	25
Brazil	163	9
Mexico	118	6
Malaysia	61	3
Philippines	39	2
Chile	35	2
South Korea	31	2
Indonesia	30	2
Thailand	24	1
48 other countries	230	13

Both UNFCCC and the KP acknowledge the world's forests as major sources of and sinks for greenhouse gases (GHG), as potential victims of Climate Change, and as important drivers for sustainable development. After all, even without counting tropical savannas and Mediterranean shrub lands, forest ecosystems store more than twice the amount of carbon contained in the atmosphere (1640 Gt C)(Sabine, Heimann et al. 2004). Net Primary Productivity of forests amounts to ca. 30 Gt C yr-1 (Sabine, Heimann et al. 2004), dwarfing fossil fuel emissions (currently ca. 7.2 Gt C yr-1) and even more so, current emission reduction obligations of industrial countries under the KP (0.173 Gt C yr^{-1}).

Figure 1. Distribution of CDM projects by continent



However, forests proved to be controversial topics during negotiations under the KP. As a result, stringent CDM rules allow only afforestation and reforestation as carbon sink projects in the land-use sector. Reducing emissions from deforestation in developing countries (REDD) was debated, but ultimately rejected on the road to the Marrakech Accords (MA).

More recently, the issue of REDD has returned with a vengeance. By now, it has become obvious that global efforts to mitigate climate change will be doomed, if emissions from deforestation and carbon stock degradation in forests are not tackled successfully and soon (Eliasch 2008). Some of these emissions undoubtedly result from disturbed bamboo stands, part of some 40 Mha worldwide. Are these emissions less harmful than carbon emissions from timber trees?

Negotiations on the roles of forests in climate change did not consider bamboos explicitly and, therefore, UNFCCC, the KP, and subsequent agreements do not refer to them. Despite the plant's vast geographical distribution, its everyday use by approximately 2.5 billion people, and its bearing on rural livelihoods, AR4's more than three thousand pages do not mention bamboos once. Likewise, the 2003 IPCC Good Practice Guidance (GPG)(IPCC 2003) ignores bamboo. The GPG proffers methods for measuring carbon stock changes in and greenhouse gas emissions from forests. For those countries that lack national activity data and parameters, it provides default values so that every member country can report its GHG as stipulated under UNFCCC. Those countries whose forests contain bamboos look in vain for applicable methods and default values for measuring their carbon stock changes and greenhouse gas emissions.

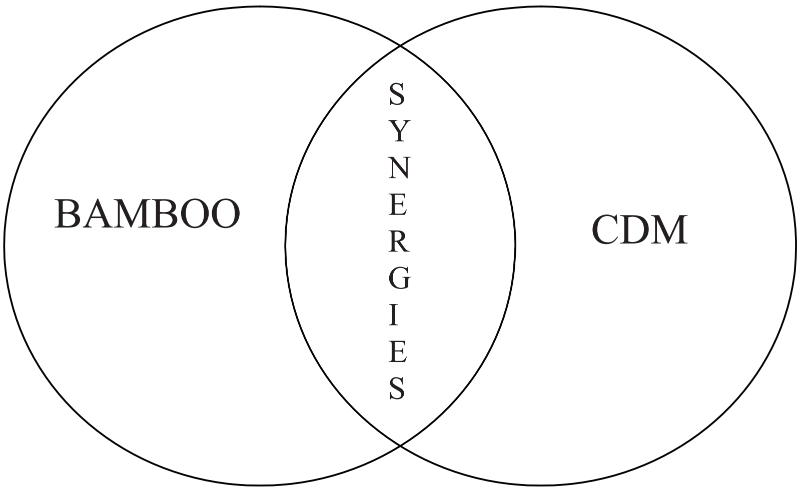
The GPG also applies to monitoring carbon stock changes in A/R projects. None of the currently registered CDM forestry projects use bamboo. Bamboo, best known as food for giant pandas, was overlooked in the negotiating process.

Conceptually this study provides a perspective on bamboo under the aspect of climate change and the CDM. Stimulating the interest of the climate change community for bamboo as a rather exceptional woody plant with intriguing properties is one objective of this study.

A second target is to update bamboo researchers and managers. Although familiar with elements of climate change and the CDM, they are unlikely to be versed in implementing the complex rules and modalities for A/R projects of the Marrakech Accords or in applying the confusing multitude of subsequent decisions to bamboo projects. Guides to A/R projects are readily accessible (Aukland, Moura Costa et al. 2002; Kaegi and Schoene 2005; Pearson, Walker et al. 2006; UNEP 2008). To avoid redundancy, only a concise briefing on A/R projects and referrals to more information are included here. Further details are woven into the relevant sections on bamboo.

The study is also not intended as a review of bamboo, nor conceived as a general compendium on forests in climate change. References exist for both topics (Liese 1985; Liese and Weiner 1996; Kleinhenz and Midmore 2001; Liese 2002; Yamin and Depledge 2004; Malhi and Phillips 2005; Freer-Smith, Broadmeadow et al. 2007; Bravo, LeMay et al. 2008; Streck, O'Sullivan et al. 2008). Instead, the text focuses on the intersection and synergies of both fields (Figure 2).

Figure 2. Concept of the study



The bamboo communities have to cooperate in implementing current climate change agreements and in negotiating for the post-Kyoto period. Under REDD, bamboo, as a wood substitute or as a component of agroforestry systems, might reduce pressures for deforestation and forest degradation as well as contribute to carbon conservation and enhancement. Under the right circumstances, bamboo might also emerge as a near flawless match to the dual goals of the CDM. Vice versa, climate change mitigation and adaptation services could complement the vast spectrum of bamboo products and services. Overall, bamboo could fill an important niche in climate change mitigation, adaptation, and sustainable development.

AFFORESTATION AND REFORESTATION PROJECTS UNDER THE CDM

The CDM of the KP allows industrialized member countries, Annex I Parties (AI), to meet part of their greenhouse gas reduction obligations through offset projects in developing, Non-Annex I countries (NAI). CDM-projects must also promote sustainable development in host countries through investment, as well as through knowledge- and technology transfer. Unilateral CDM projects by and in a NAI host country and subsequent sale of credits are feasible. Voluntary carbon offset projects involving forests and trees are not covered in this study, although they could be promising in specific contexts (Bayon, Hawn et al. 2007).

The CDM is a market-based mechanism, driven by demand for carbon offset credits - so-called certified emission reductions (CER) - from private or public entities in developed countries and by supply from carbon offset projects in host countries. CDM projects which *reduce* emissions from sources can be carried out in many sectors, particularly energy, including wood energy. However, only A/R projects which *remove* carbon from the atmosphere qualify as CDM projects. Carbon sequestration in agricultural crops and soils is not eligible for sale under the CDM in the first commitment period (CP) 2008-2012.

PREREQUISITES FOR CDM A/R PROJECTS

Host country

Countries must have ratified the Kyoto Protocol and have established a Designated National Authority (DNA) - a national institution overseeing CDM. A register of and contact coordinates for DNA's are available at UNFCCC website (UNFCCC 2009).

Prior land use

Proof must be provided that the land being utilized was not forested for at least 50 years ("afforestation") or was converted to other uses before 31.12.1989 ("reforestation") and has not been a "forest" since then (UNFCCC 2009a).

Definitions

Under the CDM, "forests" consist of trees with a height of *at least* 2-5 m, a crown cover between 10-30%, and an area between 0.05-1 ha. Countries must choose distinct values for these parameters and determine a minimum strip width of a "forest" before they can serve as hosts to A/R projects. Many have done so (Neeff, von Luepke et al. 2006, UNFCCC 2009).

Since the agreements do not define a "tree", fruit trees, bamboos, and palms may qualify in principle. A/R projects can consist of assisted natural succession to trees, productive and protective plantations, agroforestry, as well as urban tree plantings and parks. Enrichment planting or forest rehabilitation in degraded forests will not usually qualify as "reforestation", because the prior land cover was forest.

Additionality

Carbon sequestration via A/R projects must be additional to what would have occurred without the project. The Executive Board (EB) applies a stringent additionality test to project proposals. A project is generally not additional, if it is the most financially attractive among feasible options. It may still be additional if it overcomes barriers related to investments, technology or prevailing practice. The additionality criterion, rigorously applied in the interest of environmental integrity of the CDM, has doomed many proposed projects. A tool to establish or check additionality is available at UNFCCC website (UNFCCC 2009b).

Contribution to sustainable development

The host country, through its DNA decides if a proposed project contributes to sustainable development. Established DNAs and their addresses are found at UNFCCC website (UNFCCC 2009).

RULES AND MODALITIES

Baseline

A baseline for the A/R project is calculated based on the changes in carbon stocks in above-and below ground biomass, litter, soils, and deadwood that would have reasonably occurred without the project. To define a baseline, project proponents must use an approved methodology or propose a new one to which the Executive Board of the CDM (EB) must agree. This requirement has also proved to be a major hurdle for project developers. A tool is available at the UNFCCC website (UNFCCC 2009c).

Leakage

Any increase in greenhouse gas emissions, which occurs outside the project area and is measurable and attributable to the project must be minimized, monitored, and subtracted from actual net greenhouse gas removals.

Credits

Carbon offsets that have been verified and certified by an accredited, private certifying organization, a so-called Designated Operational Entity (DOE), and issued by the EB of the CDM become certified emission reductions (CER). Two types of credits take into account the possibility that trees or forests may eventually release sequestered carbon.

Temporary credits (tCER) expire at the end of the Crediting Period (CRP) following that in which they were issued, and must always be replaced by the holder to ensure continuing carbon storage. This type of credit commands a relatively low price but the producer does not pay back credits if carbon is lost as a result of calamities or harvest, even if they occur immediately after issuance.

Long-term credits (lCER) expire at the end of the project's CRP, a time of 20 years, three times renewable, or 30 years, not renewable. The holder must replace any credits that have been invalidated through premature carbon release. For lCERs, carbon released prematurely before the end of a project must be immediately replaced by permanent carbon credits or lCERs from the same project (Yamin and Depledge 2004). Prices of lCERs tend to be intermediate between those of tCERs and permanent CERs from permanent emission reductions.

Environmental impacts

Project participants must submit an analysis of expected environmental impacts to the Designated Operational Entity - DOE (UNFCCC 2009). If participants or the host country consider impacts to be significant, project proponents must undertake a formal environmental impact assessment and carry out remedial measures. Host country regulations apply.

Use of Official Development Assistance

When public funding from a developed country is used, the source must be revealed, and the sponsor country must affirm that it is not diverting regular development assistance to the CDM project.

STAGES OF AN A/R PROJECT

Local stakeholders, must be involved in the project design from the very beginning (Eddy 2005). To assist with project design, a template project design document (PDD) is available for each project type (UNFCCC 2009). Stakeholder comments on the document are solicited and published. The Designated National Authority (DNA) confirms that the host country is participating voluntarily and that the project will contribute to sustainable development. The Designated Operational Entity (DOE) checks that the project conforms to prerequisites and rules (validation), requests approval of the baseline and monitoring methods and seeks project registration. If the Executive Board of the CDM (EB) approves the project, it is registered, implemented and monitored. The Designated Operational Entity (DOE) verifies and certifies sequestration and requests the Executive Board (EB) to issue credits.

QUANTIFYING THE OFFSET

Verifiable changes in carbon stocks in all or some of the carbon pools specified in the Kyoto Protocol (KP), including aboveground biomass, belowground biomass, deadwood, litter, and soil organic carbon, form a major component of the "actual net anthropogenic greenhouse gas removals by sinks". Above-and belowground biomass usually contribute the bulk of changes. In the proposed monitoring methodology, project proponents may choose not to account for one or more carbon pools, often soil carbon, if the exclusion of these pools results in a likely conservative estimate of project greenhouse gas removals. Project proponents may freely select the time of the initial verification and certification of carbon stocks, but must follow up every five years. Changes must be verified ex-post and certified in writing by a registered Designated Operational authority (DOE). Based on the certification report, the Executive Board (EB) issues either tCERs or lCERs, as chosen by the project proponents.

Project participants might strive to maximize tCERs by choosing a cutting cycle so that certification would always coincide with peak carbon stocks immediately before harvests. However, this is counter to the rules of the CDM. The Designated Operational Authority (DOE) could not certify such a choice.

Credits are established via the approved monitoring methodology of the project, another major stumbling block for projects. They are calculated in terms of n*et anthropogenic greenhouse gas removals by sinks* in tonnes of CO_2-equivalents, i.e., *actual net greenhouse gas removal* minus *baseline net greenhouse gas removal*, minus leakage. Carbon dioxide ($CO_{2)}$ equivalents homogenize the respective global warming potentials of various green house gases (GHGs). CO_2 has an equivalent of 1, methane emission savings count 25-fold, and reduced nitrous oxide (N_2O) emissions 299-fold. Depending on contractual arrangements, all or parts of the credits may be transferred to the investor's account. The investor may keep them or trade them via emission trading mechanisms

Prices for temporary or long-term credits have not yet been firmly established. While private installations in the EU may currently not use credits from A/R projects, governments may acquire them. Carbon funds that acquire CERs from forestry activities can be found at the World Bank website (World Bank 2009).

MORE INFORMATION AND UPDATES

The UNFCCC Secretariat maintains a highly informative webpage on the CDM, with many pages dedicated to A/R projects (UNFCCC 2009). To facilitate project design and monitoring of greenhouse gas emissions and removals, the Executive Board (EB) issues and regularly updates methodological tools on its website. Table 2 illustrates recent examples. All accepted methods for baseline and monitoring for a bamboo A/R project would also be published here. They could then be transposed to other bamboo projects, as long as they match the rigorously defined applicability conditions for the approved methodology. By now, the EB has approved ten baseline-and monitoring methodologies for large-scale A/R projects. Transposing them wholly or in parts to new projects can save tens if not hundreds of thousands US dollars in project transaction and development costs.

SMALL-SCALE A/R PROJECTS

Specifically designed for prevalent rural settings in many developing countries, Small-Scale A/R Projects (SS-A/R) under the CDM are "those that are expected to result in net anthropogenic greenhouse gas removals by sinks of less than 16 kilotonnes of CO_2 per year and are developed or implemented by low-income communities and individuals as determined by the host Party."

With typical annual productivities of bamboo of between 5 and 12 t biomass per ha (Liese 1985), corresponding to 9 – 22 t CO_2 of sequestered carbon, bamboo SS-A/R projects could encompass up to 1700 ha as fully stocked stands, and up to about 9000 ha as minimally stocked stands. SS-A/R projects can be bundled, consisting of many small disjoint parcels of land belonging to different owners.

Table 2. Sample tools for designing A/R projects

Topic	Website
Estimation of emissions from clearing, burning and decay of existing vegetation due to implementation of a CDM A/R project activity	http://cdm.unfccc.int/EB/036/eb36_repan20.pdf
Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities	http://cdm.unfccc.int/EB/033/eb33_repan14.pdf
Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities	http://cdm.unfccc.int/EB/033/eb33_repan15
Estimation of direct nitrous oxide emission from nitrogen fertilization	http://cdm.unfccc.int/EB/033/eb33_repan16.pdf
Tool for testing significance of GHG emissions in A/R CDM project activities	http://cdm.unfccc.int/EB/031/eb31_repan16.pdf

Favourable rules and modalities enjoyed by SS-A/R projects are a simplified Project Design Document for a CDM project (PDD), simplified baseline and monitoring methodologies, validation, verification and certification by a single Designated Operational Entity (DOE), simplified environmental impact analysis and a shorter review period for registration. No registration fees are levied for annual net greenhouse gas removals below 15000 t CO_2, so that SS-A/R projects essentially enjoy a waiver.

To the present, the EB has approved six baseline and monitoring methods that could be transposed to future SS-A/R projects. They apply to potentially favourable settings for bamboo plantations, such as afforestation of cropland, grassland, wetland, and land in settlements, as well as agroforestry and silvopastoral settings. Due to bamboo ownership patterns, growth, yield and economics, the SS-A/R projects appear particularly well suited to facilitate bamboo CDM projects. To date, The Executive Board (EB) has registered five SS-A/R projects. None of them involves bamboo.

PROGRAMME OF ACTIVITIES

Bamboo A/R projects appear amenable to the Programme of Activities (PoA) category under the CDM, defined as:

> "a voluntary coordinated action by a private or public entity which coordinates and implements any policy/measure or stated goal (i.e. incentive schemes and voluntary programmes), which leads to anthropogenic GHG emission reductions or net anthropogenic greenhouse gas removals by sinks that are additional to any that would occur in the absence of the PoA, via an unlimited number of CDM programme activities (CPAs)".
>
> "A CPA is a single, or a set of interrelated measure(s), to reduce GHG emissions or result in net anthropogenic greenhouse gas removals by sinks, applied within a designated area defined in the baseline methodology. The applied approved methodology shall define whether the CPA is undertaken in a single facility/installation/land or undertaken in multiple facilities/installations/lands. In the case of CPAs which individually do not exceed the small-scale threshold, small-scale methodologies may be used once they have first been reviewed and, as needed, revised to account for leakage in the context of a CPA".

Countries seeking to promote rural livelihoods and/or establish a bamboo industry, with raw materials supplied from a multitude of CDM projects, might consider this new possibility under the CDM. Registering a country commitment to establish bamboo projects as a Programme of Activities (PoA) limits transaction costs, is not restricted to predefined parcels of land, and allows continuous addition of new project activities. The PoA may claim SS-A/R project advantages, as long as each CPA does not exceed the emission reduction ceiling for SS-A/R projects. Flanked by a research effort to provide missing knowledge, information, methods and parameters, such a PoA might effectively and efficiently spawn a large number of CPAs. More detail is available at the UNFCCC website (UNFCCC 2009d).

CAN BAMBOO FORM FORESTS UNDER UNFCCC AND THE KP?

The Marrakech Accord (MA), a comprehensive set of decisions by the 2001 UNFCCC Conference of the Parties (COP) on implementing the Kyoto Protocol (KP), defines forest as follows:

> "Forest is a minimum area of land of 0.05-1.0 ha with the tree crown cover (or equivalent stocking level) of more than 10-30% with trees with the potential to reach a minimum height of 2-5m at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10-30% or tree height of 2-5m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest"
>
> "Afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources".
>
> "Reforestation is "the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first CP, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989".

Neither UNFCCC nor the Kyoto Protocol define a "tree". Botanically, bamboos are grasses. Whether they should be considered a tree under UNFCCC and the Kyoto Protocol is a crucial question for the CDM, REDD, and National Communications. It is, therefore, further examined.

According to FAO, a tree is "a woody perennial with a single main stem, or, in the case of coppice, with several stems, having a more or less definite crown; includes bamboos, palms and other woody plants meeting the above criteria"(FAO 2001).

The Dictionary of Forestry (Helms 1998) defines a tree as a "woody perennial plant, typically large and with a well-defined stem or stems carrying a more or less definite crown".

The 2006 IPCC Guidelines for greenhouse gas emission inventories (IPCC 2007a), define forests in their land cover classification *inter alia* as "areas with bamboo and palms provided that height and canopy cover criteria are met" These Guidelines also offer some default values. Their glossary includes bamboos under "trees" and "woody biomass".

Clearly, herbaceous or bush forms and all those bamboos that do not reach the minimum parameters chosen by host countries cannot form a forest. On the other hand, taller bamboo species reach heights of 15-20 m; the largest culms may exceed heights of 40 m and diameters of more than 30 cm. Such tree-shaped bamboos are traditionally considered trees in a large majority of the countries harbouring them (Lobovikov, Paudel et al. 2007). In China and India, for example, where bamboo stands account for 3.3 and 9.6 Mha, respectively, they are routinely classified as forest types and covered by forest inventories.

In spite of physiological and anatomical differences between bamboos and wood trees, woody biomass from bamboos resembles that of trees and clearly differs from the biomass of grasses. As in trees, cellulose, hemicelluloses and lignin account for over 90% of total biomass. Lignin content is comparable to that of soft-and hardwoods, contributing to a high heating value and structural rigidity. Specific densities resemble those of timber trees (Seethalakshmi and Kumar 1998; Scurlock, Dayton et al. 2000; Li, Shupe et al. 2007).

Of course, bamboos with hollow culms will have both a lower volume and dry weight of solid matter per unit of culm volume.

Above all, forests are more than a collective of trees; they are ecosystems with a highly diverse plant and animal life that provide a palette of social and environmental services. Bamboo forests are rich in biodiversity and fulfill a spectrum of functions that is probably similar and conceivably richer than that of timber trees. In the context of REDD, should bamboo forests’ conversion to other land uses not be considered deforestation? Not considering bamboos as trees forming forests could single them out for conversion to other land uses, as no carbon debits would occur.

In summary, tall and medium height woody bamboos in diffuse or cluster form (see Figure3) should be accepted as trees under UNFCCC and the Kyoto Protocol, and in the future, under REDD. As long as minimum area, height, crown cover and strip width are met, areas of pure bamboo or bamboo/timber mixed stands should be considered forests.

Following these arguments, the Executive Board, in its 39th meeting, has decided that “Palm (trees) and bamboos can be considered equivalent to trees in the context of A/R”. However, it requested country Designated National Authorities (DNAs) to clarify, whether their forest definition for the CDM includes palms and/or bamboos. The Executive Board (EB) displays the information provided by countries on the UNFCCC websites (UNFCCC 2009). Up to now, only the Philippines and Cambodia have amended their forest definition to include bamboos. It is still unclear, if bamboos will also be considered as trees under REDD and in National Communications under UNFCCC.

Several ramifications of treating bamboos as trees emerge:

Sites that are void of timber trees or seriously degraded, but sustain natural bamboos meeting the forest criteria above, would be ineligible for A/R projects, since they are already considered forests.

Afforestation and reforestation, by the preceding definitions, can occur through planting, seeding and “human-induced promotion of natural seed sources”. The latter term, whatever it means, does not cover assisted succession via rhizomes (Neeff, von Luepke et al. 2006). Any assisted natural succession to bamboo on non-forest lands by rhizomes would, verbatim, not constitute afforestation or reforestation and disallow such A/R projects. The Executive Board might have to clarify this.

BAMBOO CHARACTERISTICS FOR A/R PROJECTS

Developers of A/R projects need not become bamboo experts, but might benefit from familiarity with bamboo features which may affect choice, type, design, baseline- and monitoring methodologies and economic prospects of projects. Basic knowledge of bamboos may also help to improve future climate change agreements.

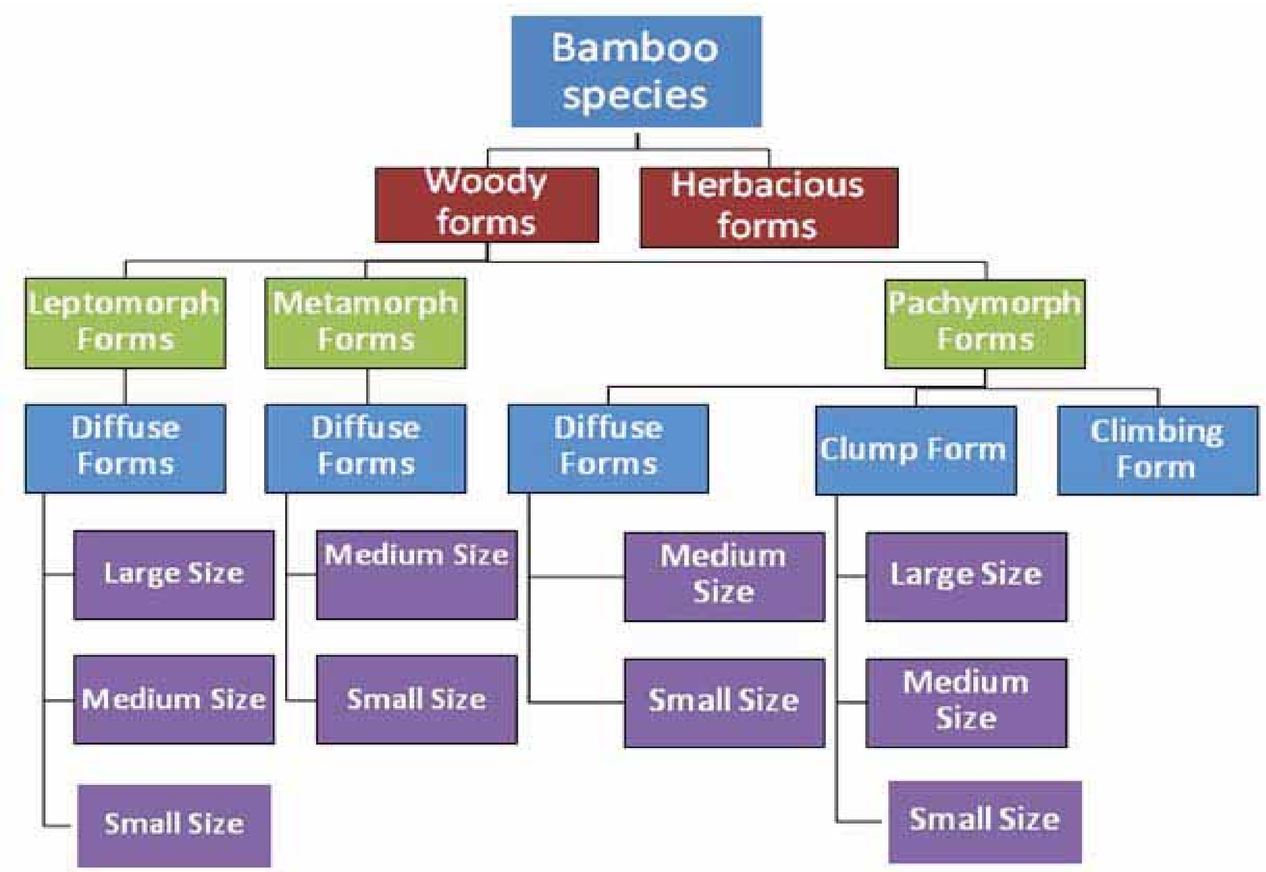
TAXONOMY, STRUCTURE, EMERGENCE

Bamboo is a vernacular term designating plants of the taxonomic family of grasses, Poaceae, subfamily Bambusoideae, related to wheat, rye, barley, oats, rice, corn and sugar cane. There are approximately 1,250 species in 90 genera (Scurlock, Dayton et al. 2000; Dura and Hiura 2006; Lobovikov, Paudel et al. 2007) ranging in size from dwarf species, growing only 10 cm high, to giant canes, towering well above many tree heights in temperate forests.

Not all are equally important in the context of this study. The International Network for Bamboo and Rattan (INBAR) has compiled a priority list of bamboo species based on social, ecological and economic criteria with details on distribution, climate and site requirements, domestication and current information status (Williams, Ramanatha Rao et al. 1994). The list identifies an untapped potential for rehabilitating degraded wastelands with bamboo, see Appendix II (INBAR 2009).

Although bamboo herbaceous life forms exist, most bamboos are woody plants. Figure 3 presents a classification scheme by fundamental life form, propagation, growth form and culm height (Watanabe 1995).

Figure 3. Bamboo classification



The main structural parts of a bamboo plant are the underground system of solid or hollow rhizomes, the aboveground culms, and the culm branches with their sheaths and leaves. Rhizomes are not roots, but underground shoots. Colorless storage- and propagation organs, they have dense, fibrous roots and branch off the mother plant, thus colonizing new territory. Two main types of rhizomes exist and determine the habitus of the bamboo species. Monopodial or leptomorph rhizomes grow away from the mother plant, often at a surprisingly fast rate, thus their nickname of 'runners'. Total length of these underground rhizomes may reach 50-100 km/ha (Liese 1985). The rhizome buds develop either upward, generating a culm, or horizontally to extend the rhizome axis. These monopodial bamboos produce individual culms from the main axis, at a distance from each other. Buds close to the mother plant produce larger and more viable culms, whereas culms that are more distant may be so weak as to eventually die back. Monopodial bamboos are usually found in temperate regions and tend to be invasive to the extent that protective measures might be needed to prevent undesirable spreading.

Sympodial or pachymorph rhizomes are short and thick, forming culms in a compact clump spaced closely around the mother plant. Sympodial bamboos predominate in the tropics, are not invasive, and generally more productive than monopodial species.

With the onset of warm weather, buds on the rhizomes lengthen into an upright shoot with a sharp point that penetrates the ground. The emerging bamboo shoot maintains its diameter throughout its life. As the new culm grows, a protective sheath, attached to the preceding node at the sheath ring, wraps each new internode. The sheath eventually dries and contributes to litter. Culms consist of consecutive massive nodes and usually, but not always, hollow internodes (Seethalakshmi and Kumar 1998; Embaye, Weih et al. 2005). Commonly, solid culms are designated as "male"; hollow ones as "female". Once the internode has lengthened, it does not extend any further. Under optimal conditions, culms may elongate 50-125 cm a week, even up to 90-120 cm per day and reach final height within 2-4 months (Liese 1985; Seethalakshmi and Kumar 1998; Scurlock, Dayton et al. 2000; Dura and Hiura 2006). The height that a shoot reaches in its first year is also its final dimension.

Mostly, branches emerge from the nodes after culms reach maximum height. However, the number of leaves and branches may still increase in subsequent years. Leaves are shed at the end of the first or following growing season. There is a continuum of deciduous to evergreen bamboos, and species may change their habit depending on sites (Yang, Duan et al. 2008). A biennial pattern of good and poor growing years determines shoot production in some species. Leaf area index (LAI), of mature bamboo stands is comparable to that of stands of trees, e.g. 8-12 (Isagi, Kawahara et al. 1997; Embaye 2001). In trees, this LAI suffices to absorb up to 95% of incident solar radiation, and maximize net primary productivity (Kramer and Kozlowski 1979).

No explicit reference was found on the albedo of bamboo stands, that is, the fraction of short wave incipient radiation reflected back to the atmosphere by the canopy, a parameter characterizing the geophysical effects of bamboo stands on warming. Bamboo species with glossy leaves and culms might have a high albedo, causing less warming. Further studies might test this hypothesis.

When new culms emerge, storage tissues in the existing system of rhizomes mobilize carbohydrates for shoot elongation. Thus, aboveground biomass will increase at the expense of belowground biomass. Only after culms and new leaves are fully grown, will the plant replenish carbohydrate stocks in the rhizomes and extend the rhizome system.

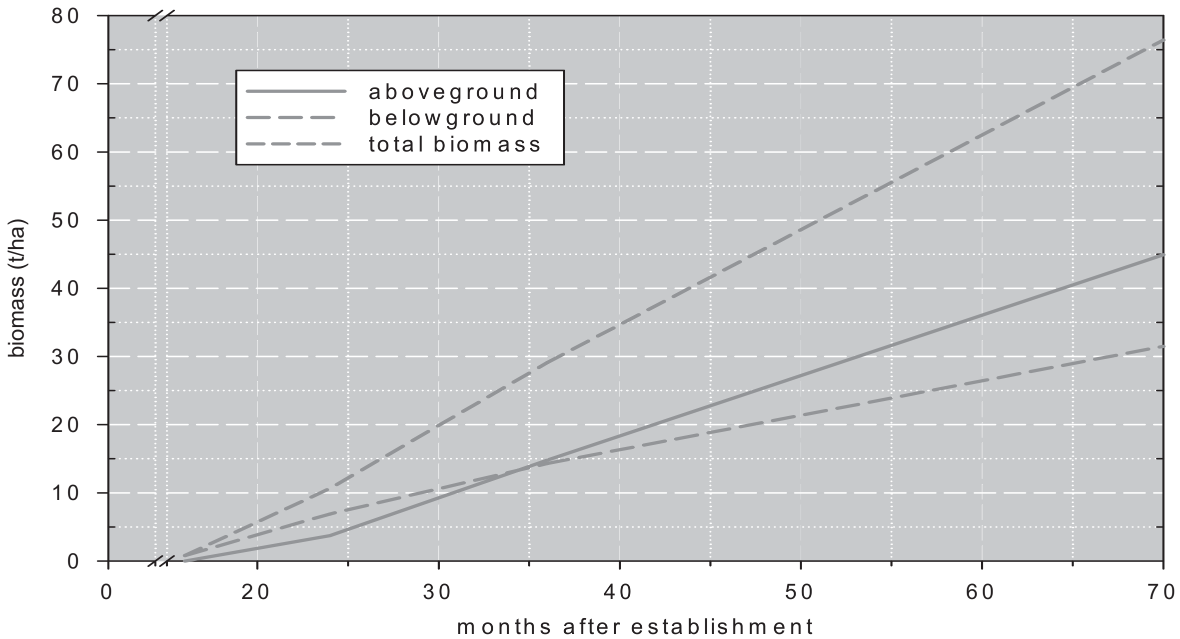
GROWTH PATTERNS

In contrast to trees, there is essentially no volume increment of the individual culm after the first year. However, as individual culms mature, they undergo chemical and structural changes during maturation that affect their physical properties. Cell walls continue to acquire silica and lignify for up to seven years (Li, Shupe et al. 2007). Therefore, some increase in biomass of individual culms takes place. In one reported example, air-dried specific gravity of maturing culms increased by about 60% over five years, (Li, Shupe et al. 2007). Aboveground biomass growth and carbon sequestration in bamboo, therefore, has two components: growth of newly emerging culms and biomass increase in older culms.

During their senescence, culms will typically spawn few young shoots. Over-mature culms start decaying after about 8-10 years of age; together with the shoots, rhizomes and roots will also die (Lakshmana 1991).

In contrast, after culm harvest, large parts of the belowground biomass survive, preserving much of the sequestered carbon (Christanty, Kimmins et al. 1997). This is a distinct advantage that bamboo CDM projects have over those involving timber trees, where, with the exception of species forming root suckers or stump sprouts, roots die after felling. Belowground bamboo biomass can increase so steeply, that measuring changes in belowground carbon might be cost effective (Figure 4).

Figure 4. Cumulative biomass of planted bamboo after establishment



For some bamboo species, experts can identify culms of equal age by their outward appearance (Veblen, Schlegel et al. 1980; Lakshmana 1991; Wan and Mohamed 1994). For other species, age needs to be indicated with paint as culms emerge. Established stands of bamboo will typically encompass about 2000 to 10000 culms of different ages per ha. Species, site, and human or natural disturbances are among the factors that will determine culm density and age composition, comparable to uneven-aged stands of timber trees. However, in counterintuitive contrast to trees, younger, more recent culms of a bamboo clump tend to be taller and thicker than older ones, since a more vigorous mother plant produces them (Watanabe 1995; Castaneda-Mendoza, Vargas-Hernandez et al. 2005). A/R project monitoring methods for carbon must match bamboo growth patterns, culm- and stand structure. More detail follows.

RELEVANT PHYSIOLOGICAL FEATURES

In contrast to grasses, for example sugar cane, maize, millet, and savanna grasses, but like most timber trees, bamboos are C_3-plants (Jones 1985 ; Scurlock, Dayton et al. 2000), lacking the C_4 photosynthetic pathway (Kramer and Kozlowski 1979; Larcher 1995). In the C3-pathway of carbon dioxide assimilation during photosynthesis, CO2 is bound in molecules that contain three carbon atoms (phosphoglyceric acid). In roughly 10% of all plant species, the first product of CO2 assimilation is a molecule with four C-atoms (oxaloacetic acid), hence the name C4-plants.

Noteworthy, bamboos have a below-normal capacity to increase photosynthesis when exposed to optimal light intensities, water supplies and temperature regimes; under such conditions, most tree species increase net photosynthesis much more than do bamboos (Larcher 1995). No specific studies expounding on these important aspects were found.

However, in the absence of other limiting factors, bamboos as C_3 plants should be able to increase net primary productivity (but not necessarily net ecosystem productivity and ecosystem carbon sequestration) in response to CO_2-enriched atmosphere (Körner, Morgan et al. 2007). Compared to C_4- grasses, bamboos should be more sensitive to drought, have higher nitrogen demand, and tolerate cold better. Temperate species would be sensitive to very high temperatures, an effect perhaps observed in exotic bamboos grown in Italy (Gratani, Crescente et al. 2008).

Bamboos apparently have relatively low photorespiration and high photosynthetic efficiency (Dura and Hiura 2006). It appears dubious, that, as sometimes claimed (Marsh and Smith 2007), bamboos really release 35% more oxygen than an equivalent area of trees.

Carbon sequestration is currently the main criterion employed to rate effectiveness of climate change mitigation of growing forests, although fluxes of other GHG, e.g. emissions of methane or nitrous oxides from soils, may reduce actual net greenhouse gas removals by CDM projects. As it turns out, even this measure may be simplistic. Plants, particularly those from tropical rain forests, release methane to the atmosphere, a process discovered only recently (Keppler 2006; Keppler, Hamilton et al. 2006; Keppler, Hamilton et al. 2008). Subsequent confirmation of this surprising observation revealed that a bamboo, phyllostachys aurea, releases methane as well (Vigano, Van Weelden et al. 2008).

Many plants, tree species among them, also emit Non-Methane Organic Volatile Compounds (NMVOC). In polluted air containing nitrous oxides, NMVOCs contribute to photochemical smog and formation of ozone, a potent greenhouse gas. In pure air, NMVOCs deplete the atmosphere of hydroxyl-groups (OH^-), thereby prolonging the lifetime of methane in the atmosphere, and, again, enhancing warming. Bamboos emit much isoprene, one of these NMVOCs (Loreto, Centritto et al. 2002). As observed in parts of China, bamboos in city parks contribute to smog and high ozone concentrations (Wang, Han et al. 2007; Wang, Han et al. 2008). If such emissions were confirmed for all bamboo species, net greenhouse gas removals by bamboo forests as currently calculated would overestimate net climate change mitigation to some extent.

Bamboos produce other relevant compounds. Root excretions can suppress growth of other plants, e.g. maize, groundnuts, or other understory species (allelopathy) (Liese 1985; Seethalakshmi and Kumar 1998). Young shoots of some bamboo species contain significant amounts of a toxic cyanide, taxiphyllin. Fortunately, this toxin degrades rapidly in boiling water during normal preparation of edible bamboo shoots (Hunter and Yang 2002).

Bamboos accumulate on the average 0.1-2.8% of their dry weight as silica in the epidermis of the culm and, particularly in older leaves, reaching over 40% in some species (Motomura, Hikosaka et al. 2008). In contrast, nodes and internodal tissues are free of silicon dioxide (Seethalakshmi and Kumar 1998), an advantage for processing, since silica raises ash content and dulls cutting tools.

With 0.3-5.3% of ash, bamboos approximate tropical tree species (Knigge and Schulz 1966, p.70). They contain more ash than temperate woods (0.3-1%), but less than some bioenergy grasses, e.g. Miscanthus giganteus or Panicum virgatum (switchgrass). Among the chemical peculiarities of bamboo is a low chlorine content, favourable in industrial bamboo biomass combustion. The moisture content in the air-dry state of 8-15% is lower than that of timber species (Scurlock, Dayton et al. 2000; Nakagawa, Harada et al. 2007).

In summary, bamboo physiology is conducive to high productivity and substantial carbon removals from the atmosphere. Pending further research, increased atmospheric concentrations of CO_2 should enhance carbon sequestration. Parties will also have to decide if emissions of methane and/or NMVOC by bamboos (and other tree species) should be considered in actual net greenhouse gas removals in a future Climate Change regime. Allelopathic properties of bamboos and cyanide content could affect agroforestry projects. Bamboo has some desirable biofuel characteristics.

ENVIRONMENTAL EFFECTS

Prospective environmental effects of a proposed A/R project represent an important part of its Project Design Document (PDD) for a CDM project, subject to public scrutiny and comment. Bamboos could enhance biodiversity, since, according to the rules of the CDM, project sites must not have been forested since 1990. Biodiversity may include veritable micro-ecosystems within the hollow culms (Louton, Gelhaus et al. 1996; Davidson, Castro-Delgado et al. 2006; Kaufmann and Maschwitz 2006). Besides the popular giant panda, other animals such as the red panda, and over 20 bird species (Seethalakshmi and Kumar 1998; Schoonover and Williard 2003; Bitariho and McNeilage 2007; Hooda, Gera et al. 2007; Lobovikov, Paudel et al. 2007; Widenoja 2007; Anonymus undated) depend exclusively or partially on bamboo. Some bats nest in culms and some rodents live exclusively in bamboo stands, where flowering and seeding can lead to a population explosion and subsequent famine for the rodents. Bamboo shoots are delicacies not only for humans, but also for orangutans, elephants, deer and squirrels.

Bamboo A/R projects need not be monocultures; optimal silvicultural and agroforestry options have been described previously. Bamboos have also been observed to naturally enhance woody species richness (Larpkern, Moe et al. 2008). Certain bamboo species themselves are on the lists of endangered species, over 20 of them in Central and South America (Lobovikov, Paudel et al. 2007).

By accumulating organic matter and counteracting erosion, bamboos have reversed soil degradation in exploited landscapes (Christanty, Kimmins et al. 1997; Zhaohua and Yang 2004; Singh, Zeng et al. 2006; Hooda, Gera et al. 2007; Marsh and Smith 2007; Mohamed, Hall et al. 2007). They can regulate water flows (Marsh and Smith 2007), reduce sedimentation and pollution from agricultural runoff and filter waste water (Schoonover, Williard et al. 2006; Marsh and Smith 2007; Vigiak, Ribolzi et al. 2007). Bamboo stands, as natural rafts or tightly woven root mats, offer shelter against earthquakes, floods and tsunamis.

However, not all environmental effects of bamboo are beneficial or benign. Monopodial bamboos can be invasive to the extent that tough root barriers are needed to prevent undesirable spreading. The rules of the CDM leave it up to the investor and/or host countries to accept or exclude invasives. Bamboos have caused slope failures due to dense root mats in upper soil horizons (Dura and Hiura 2006; Lu, Liu et al. 2007). As detailed previously, they may emit methane or isoprene and contribute directly or indirectly to warming.

SOCIO-ECONOMIC EFFECTS

Even in the absence of carbon payments, bamboo plantations can be profitable. Concerted efforts by central and local governments, private industry, research institutions and rural people to establish a viable bamboo industry have produced striking results, significantly reducing poverty, boosting employment and regional development (Marsh and Smith 2007).

Bamboos provide raw material for about 1500 known commercial products (Scurlock, Dayton et al. 2000). These range from handicrafts, such as woven baskets, to edible bamboo shoots produced by about 200 species, to high value industrial goods, such as pulp, paper and textiles, bio-fuels, charcoal, housing, panels, flooring and furniture (Lobovikov, Paudel et al. 2007).

Annual removals from bamboo forests may reach 1.4 billion tonnes in the main producer countries (Lobovikov, Paudel et al. 2007), but are most likely much higher due to unrecorded local use. After pre-processing and sorting the bamboo harvest into different supply chains, virtually all parts of the raw material find their way into commercial products. By comparison, in many developing countries converting standing timber trees into wood products recovers as little as 20% of the original aboveground biomass (Muladi 1996). In addition, the entire integrated supply chain for bamboo products creates a high percentage of jobs in or near rural communities and employs many women.

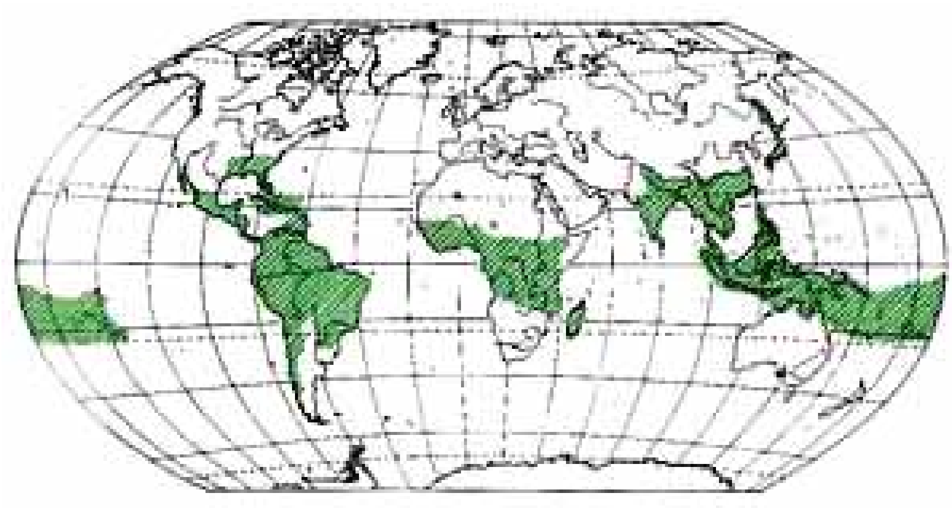
On the average, 75% of total revenues from such supply chains benefit the poor, farmers and local workers at the point of origin of the raw material. Even large-scale pulp and paper production from bamboo incurs 35% of total costs near the raw material source. Newly established bamboo industries in China have created 0.2-0.5 jobs/ha with a local, pro-poor financial impact of between US $400 and $800/ha.

Profit margins in bamboo processing industries typically amount to from 7% to 12%, even in the absence of carbon offset payments. Integrated bamboo industries provide not only revenues, but also powerful environmental and social stimuli for development (Duraisamy 2003; Yang and Sucuiwei 2004; Zhaohua and Yang 2004; Marsh and Smith 2007; Pachauri 2007).

WORLDWIDE DISTRIBUTION

Bamboos grow naturally in the tropical and sub-tropical regions between 46° North and 47° South on all continents, except Europe, and from sea level to 4000m elevation (Scurlock, Dayton et al. 2000), Figure 5.

Figure 5. Global distribution of bamboo species



Globally, bamboo forests grow on at least 37 Mha (Lobovikov, Paudel et al. 2007) and make up 3.2 % of the forest areas of their host countries, and about 1% of the global forest area. India, China, Indonesia, Ecuador, Myanmar, and Vietnam have the largest bamboo resources of 25 countries recently surveyed (Lobovikov, Paudel et al. 2007). Their Designated National Authorities (DNAs) have yet to accept bamboos as "trees". About 80% of inventoried bamboo forests and, by coincidence, an equal proportion of all bamboo species grow in the Asia-Pacific region, from India to the eastern side of the Islands of Oceania, and from Japan to New Zealand. About 80% of the species are sympodial. More than 100 species are tall with high culm quality and high economic value. In Australasia and Oceania, bamboos are less abundant.

In South- and Central America, 300 species of 20 genera abound. The most important species, Guadua angustifolia, is widely used in Colombia, Ecuador, Nicaragua, Venezuela, and Honduras. Asian bamboos grow as exotic species over much of Latin America and the southern part of North America. Central America alone harbors 35 introduced species of eight genera.

Bamboos are indigenous to Africa in a range from southern Mozambique to Sudan, including Nigeria, Cameroon, Gabon, Congo, Zaire, Uganda, Kenya, Tanzania, Mozambique and Madagascar. However, there are few native species, belonging to the genera Oreobambos, Oxytenenthera and Arundinaria. They occasionally form large natural forests, such as those of Arundinaria alpina in Kenya and Oxytenanthera abyssinica in Ethiopia with 130,000 ha and 100,000 ha, respectively. Madagascar, with 11 genera and approximately 40 species is particularly rich in bamboos.

Due to poor definitions, rudimentary forest inventories and neglect of the resource, data on bamboo areas are notoriously unreliable. In a top-down study, the forest area where woody bamboos could potentially grow well when introduced has been estimated as about 2.5 billion ha for Asia, Oceania, Africa and Latin America (Bystriakova, Kapos et al. 2001; Bystriakova, Kapos et al. 2002).

Bamboos often form parts of planted forests. Planted native bamboos regenerated over six Mha of Asia's 21 Mha of bamboo forests. Large planted forests of native bamboo also exist in Africa (Ethiopia, Nigeria, Kenya), and Latin America (Ecuador, Mexico, Brazil, Peru, Costa Rica, Colombia, Puerto Rico). A recent study lists 326,000 ha in Sudan and 184,000 ha of productive and protective bamboo plantations in Vietnam (Del Lungo, Ball et al. 2006).

The U.S.A introduced Asian bamboos as early as 1860. Only one of bamboo species, Arundinacea gigantea, is native (Scurlock, Dayton et al. 2000). The genus Arundinacea is also the only one that grows in both hemispheres. However, a newer study counts three native American bamboos (Albani, Medvigy et al. 2006). Bamboos have also been planted widely and thrive as exotics in European parks and gardens (Jauch and Kiermeier 2009).

OWNERSHIP PATTERNS

Global forests are still predominantly a government domain. Worldwide, 85% of forests are still public property, with 95% of Asian, 98% of African, and 76% of South American forests publicly owned. As opposed to this, almost two thirds of bamboo stands in major bamboo countries are privately owned (Lobovikov, Paudel et al. 2007). In Papua New Guinea, Pakistan, Korea and Japan, essentially all bamboo forests are private. In many cases, the rural poor have access to natural bamboo resources on community or public lands, but they also cultivate bamboo in small patches of marginal land for their own use. Therefore, bamboo appears well suited to SSA/R projects. In China, where all land is public, the government has boosted bamboo silviculture by allotting one third of the bamboo forest to private owners through long-term leases.

Ownership patterns of bamboo worldwide reflect its role as the “poor man’s timber”, indicating rural peoples’ interest in and capacity for bamboo management and its important functions in rural livelihoods.

BAMBOO SILVICULTURE AND MANAGEMENT

SITE REQUIREMENTS OF BAMBOO

Forest site quality usually depends mainly on mean annual and/or seasonal temperature, annual or seasonal precipitation, available water capacity of the soil and soil fertility. Special properties, such as extreme temperatures, altitude, slope and aspect, waterlogging, compaction, or high pH values may amplify the effects of these primary factors.

Most bamboos require relatively warm and humid conditions, e.g. a mean annual temperature of 15-30° C and annual precipitation of about 1000-2000 mm, with a range from 700-6000 mm (Liese 1985; Seethalakshmi and Kumar 1998; Scurlock, Dayton et al. 2000). Some bamboos also tolerate heat of between 40 and 50^0 C (Liese 1985). Others are quite tolerant of cold (Hunter 2003). Some monopodial bamboos are hardy to about minus 20^0 C and grow productively in Northern California, Pennsylvania, and Korea. Species from temperate zones even carry on photosynthesis in winter (Gratani, Crescente et al. 2008; Jauch and Kiermeier 2009). Sympodial bamboos cannot tolerate freezing temperatures.

Bamboos also grow in the dry tropics, even on shallow degraded soils (Singh, Zeng et al. 2006). In fact, bamboo plantations are often attractive options for marginal or degraded land (Patil, Patil et al. 1991; Hunter 2003; Yang 2004; Zhaohua and Yang 2004). They may actually improve such sites by accumulating high amounts of soil organic matter through their decomposing leaf and abundant fine root litter (Christanty, Mailly et al. 1996; Mailly, Christanty et al. 1997; Das and Chaturvedi 2006b). However, poor sites clearly constrain productivity, carbon sequestration and growing stocks. Productivity and rates of carbon sequestration by species may triple on the best sites (Virtucio, Manipula et al. 1991; Virtucio and Tomboc 1991; Watanabe 1995). Few bamboos can tolerate soils with impeded drainage (Veblen, Schlegel et al. 1980; Chen, Wu et al. 2001; Othman 2002; Vazquez-Lopez, Vibrans et al. 2004) and they prefer slightly acid soils with a pH from 5.0 to 6.5.

STAND MANAGEMENT

Requiring only about seven years, planted bamboo forests grow to maturity much faster than most timber trees. During this period, bamboo stands pass from the establishment stage through phases of tending-, pre-commercial and commercial thinning, and harvesting. Each stage requires specific silvicultural interventions.

Afforestation/reforestation phase

Afforestation and reforestation of bamboos consists of sowing, or planting nursery-grown seedlings, and will often employ vegetatively propagated material, such as cuttings of clumps or rhizomes, rooted culms, nodes or branches, or plants raised by tissue culture. Often, local experience and guidelines can detail options for priority species (Seethalakshmi and Kumar 1998, INBAR 2009, CABI 2009a).

The Executive Board (EB) would most likely accept regeneration through rhizome runners from adjacent stands, as long as direct human intervention, such as fencing, weeding, protection against animal grazing, can be documented (as discussed before).

During this establishment phase, the main bamboo species and associated, understory, and possibly agroforestry species are chosen. Planting densities, soil and site preparation, weeding, fertilization, mulching, mounding, re-planting, fill-planting or protection from browsing and trampling by wildlife and livestock are other potentially necessary interventions.

Bamboo monocultures are environmentally often less desirable than mixed stands with nitrogen-fixing trees, fruit trees, teak, or agroforestry species (Fu, Jinhe et al. 1991; Watanabe 1995; Christanty, Kimmins et al. 1997; Marsh and Smith 2007). Mixing species may enhance carbon sequestration, be attractive for investors, and improve chances for project registration. Mixed stands of bamboo and conifer or broadleaf trees can produce higher growth rates and better quality of both species groups (Fu, Jinhe et al. 1991). In

China, agroforestry systems have very successfully combined bamboo species with tea, as well as with crops, such as watermelon, soybeans, sweet potatoes, sugar cane and vegetables, with fish pond management, and with production of edible fungi and medicinal plants (Fu, Jinhe et al. 1991).

Planting densities depend on species, site, and economic goals. For monopodial species, common densities range from 1000 to 2500 plants per ha; for pachymorph bamboos, from 150 to 300 clumps per ha. Dense stands will generally produce more biomass and sequester more carbon, but often at the expense of culm quality and dimensions (Patil, Patil et al. 1991). An overall economically optimal stand density will depend on net revenue streams from bamboo products and carbon services. Few reliable data are currently available for decisions ex ante.

Some activities, such as site preparation or mounding for better growth and initial survival, stimulate organic matter decomposition and release GHG, particularly CO_2. Emissions from motorized transport must also be monitored, documented and accounted. Soil compaction from excessive or untimely vehicle traffic can promote emissions of methane, a greenhouse gas roughly 25 times more powerful than CO_2. In addition, applications of nitrogen releases nitrous oxide (N_2O), a greenhouse gas whose global warming potential exceeds that of CO_2 299 times.

Precommercial thinning and tending of young stands

These interventions eliminate malformed or diseased culms, control stocking density and species mix and remove climbers. Unless a separate bioenergy CDM project is registered, reduced fossil fuel emissions through biofuel use of such materials will not create additional credits. Early returns may occur from thinnings, agroforestry species and edible bamboo-shoots.

Thinning and selective harvesting

Although there are reports to the contrary (Patil, Patil et al. 1991; Scurlock, Dayton et al. 2000), clearcutting of bamboo is rarely recommended, except for small species, or for salvaging flowering stands (Liese 1985; Scurlock, Dayton et al. 2000). Species differ in their response to clearcutting. Clearcutting bamboo stands decreases vitality (Liese 1985; Christanty, Kimmins et al. 1997; Wadsworth 1997; Nath, Das et al. 2006), or kills at least some rhizomes (Virtucio and Tomboc 1991; Wan and Mohamed 1994; Bitariho and McNeilage 2007).

Selective harvesting of bamboo stands resembles uneven-aged forest management for timber species. In bamboo forests, management may, therefore, employ some of the same concepts and techniques. Uneven-aged management is characterized by felling cycles, that is, the periodic return of harvest operations, and felling intensities, the amount and age-structure of removed culms. Felling cycles of 2-4 years are common, removing 50-70% of mature culms, but leaving young, immature culms untouched. Cutting techniques open up clumps for future access. Selective harvesting in short cycles, even annually, is particularly important for low-income owners, as it yields a steady stream of revenues and provides self employment.

A target stand structure, prescribing the desirable age structure in terms of percentages of culms of each age, should be established, e.g. 10:20:30:40 for a 4-year cutting cycle (Wan and Mohamed 1994; Embaye, Weih et al. 2005; Nath, Das et al. 2006). Harvest cycles improve stand vitality and new culm production by avoiding overcrowding and mortality (Virtucio and Tomboc 1991; Seethalakshmi and Kumar 1998; Bitariho and McNeilage 2007). However, sufficient mature culms must remain to nurture new shoots and provide stability against wind-throw and bending of emerging shoots. Just like in uneven-aged forest management, age-class distribution and yield will ideally remain approximately constant over the long-term.

Bamboo nutrition

Biomass removals under short felling cycles export large amounts of plant nutrients, which need to be compensated by either chemical fertilizers or organic amendments. Bamboo has a particularly high requirement for and high leaf concentration of potassium, often exceeding that of nitrogen (Virtucio, Manipula et al. 1991; Chandrashekara 1996; Mailly, Christanty et al. 1997; Hunter and Wu 2002; Venkatesh, Bhatt et al. 2005; Lehmann, Gaunt et al. 2006).

Bamboos respond particularly well to applications of manures (Christanty, Mailly et al. 1996; Christanty, Kimmins et al. 1997; Upadhyaya, Arunachalam et al. 2004; Razak and Ismail 2006; Wu, Wu et al. 2006; Zhou, Xu et al. 2006). These and abundant fine root litter will gradually enrich the soil with nutrients and enhance the soil carbon pool (Patil, Patil et al. 1991; Li, Fu et al. 2006). Reported increases in soil organic matter under bamboo of 1-3 t yr^{-1} ha^{-1} (Christanty, Mailly et al. 1996; Christanty, Kimmins et al. 1997; Singh, Zeng et al. 2006; Wu, Wu et al. 2006; Tian, Justicia et al. 2007) exceed usual organic matter accumulation in most forest soils. Without amendments, soil carbon may decrease under intensive management (Venkatesh, Bhatt et al. 2005; Li, Fu et al. 2006; Zhou, Xu et al. 2006). Therefore, a bamboo A/R project should disregard the soil carbon pool only after some deliberation.

Bio-char (charcoal) from bamboo is a particularly effective soil amendment, which not only sequesters carbon in a very stable form in soils, but can serve as a reservoir of water and nutrients (Sombroek, Nachtergaele et al. 1993; Okimori, Ogawa et al. 2003; Forbes, Raison et al. 2006; Lehmann, Gaunt et al. 2006; Fearnside, Barbosa et al. 2007; Razak, Janshah et al. 2007).

Bamboo stands integrated into agricultural systems, such as the talun-kebun system of West Java where crop production and bamboo cultivation alternate periodically, are highly effective in refurbishing the fertility of depleted agricultural soils, thereby curbing the use of short fallow period shifting cultivation. Acting like nutrient pumps, bamboos recover nutrients from subsoil horizons, accumulating them at the surface in available form (Christanty, Kimmins et al. 1997). Bamboo litter on the soil surface is resistant to decay due to its structure and high silica content, preventing nutrient leaching and accumulating additional carbon in litter and soil organic matter (Chandrashekara 1996; Christanty, Mailly et al. 1996; Mailly, Christanty et al. 1997; Embaye, Weih et al. 2005; Gao and Fu 2005; Das and Chaturvedi 2006a; Das and Chaturvedi 2006b; Lu, Liu et al. 2007).

In summary, bamboo silviculture and management appear well suited to small rural land ownerships. Yields occur relatively early and at short intervals thereafter. Clearcutting is usually not an option and selective harvesting provides a continuing stream of income, without reducing revenue from the sale of CERs. Bamboo silviculture creates a continuous demand for manual and low-tech labour. Harvesting, skidding, yarding and transporting culms are labour intensive, creating local or self employment. Carbon sequestration in biomass and soils can be enhanced by using locally available organic amendments. Insects, diseases and the impacts of climate change represent moderate risks (Liese 1985). These can be reduced further by opting for tCERs. Bamboo stands can deliver a wide palette of products, including edible shoots and even fruits. Bamboo seems tailor-made for SS-A/R projects.

BAMBOO RISKS

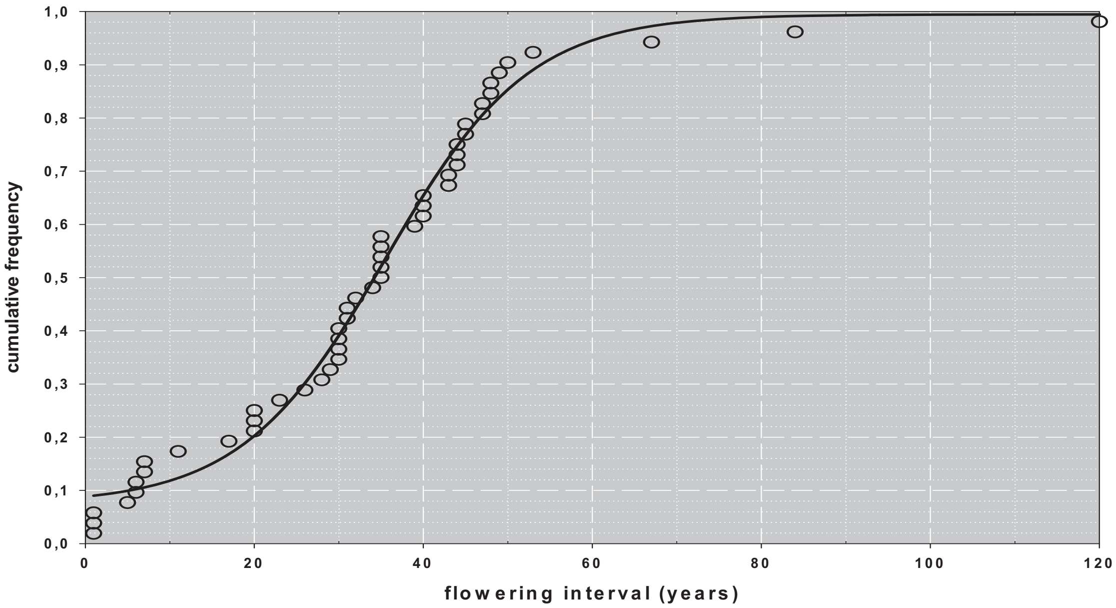
Risks from bamboo mass flowering

Periodic mass or gregarious flowering of bamboo may result in complete dieback and loss of the culms. In such cases, most of the sequestered carbon from above- and belowground biomass, as well as some carbon in litter and soil, is released. However, media reports of declining panda populations after bamboo dieback have contributed to the simplistic view that all bamboos flower gregariously and die off afterwards (Sharma 1991).

The type of flowering in bamboos varies not only widely by species, but can occur gregariously and/or sporadically within the same species, probably involving two different triggering mechanisms. Consequences, such as the production of seeds and/or the survival of the flowering stand above- and belowground also vary, creating a confusing palette of possible outcomes. Some bamboos remain and propagate in the purely vegetative state for centuries. Bambusa vulgaris, for instance, has apparently not flowered gregariously since 1810 in India. In the other extreme, species may flower annually without producing viable seeds or without dying back.

The majority of bamboos do flower gregariously with cyclic recurrence from every few years up to more than 100 years apart. Cycles for most species are known, but may differ by region or site (Sharma 1991; Seethalakshmi and Kumar 1998; Bitariho and McNeilage 2007). In a literature sample, the median flowering interval of bamboo species is 35 years. According to the sample distribution, forty percent of bamboo species can be expected to flower at least once during a 30-year Crediting Period (CRP), and 95% during a 60-year project lifetime (Figure 6). Therefore, species choice is important. Mass flowering involves all cohorts, independent of culm age. Natural dieback after gregarious flowering takes 2-3 years.

Figure 6. Distribution function of bamboo mass flowering intervals



Global warming is thought to increase the frequency of El Niño events and mass flowering of tropical seasonal forests in Asia (Sakai, Harrison et al. 2006). It is still unclear, if this also applies to bamboo. However, high temperatures and prolonged drought may induce bamboo species with cyclic flowering to bloom sporadically as well. They may then produce viable seeds that are particularly important for regenerating stands that are out of phase with the cycles of gregarious flowering of the mother population. Prior disturbance by fire can result in total loss of the seed crop, even if mass flowering does occur (Li and Denich 2002).

The risk of stand, product, and carbon loss from flowering and mass dying in A/R projects is lower than conventional wisdom presumes. Usually, gregarious flowering is near, if production of new culms slows or ceases and/or some sporadic flowering of culms occurs. Hence, preparation for harvest and salvage before stands may die off is sometimes possible. Fertilizing with nitrogen and clearcutting can prevent gregarious flowering and dieback of the belowground system (Sharma 1991). Employing uneven-aged genets in a project can also minimize risk (Scurlock, Dayton et al. 2000).

To further reduce risk, project participants can select a suitable type of Certified Emission Reduction (CER). Should they choose Longterm Certified Emission Reduction (lCERs), credit holders would have to immediately replace any carbon lost prematurely. A better choice would be Temporary Certified Emission Reduction (tCERs). Carbon lost since the last verification would not need to be replaced. Instead, no new tCERs would be issued for the lost carbon.

Other risks

Fire and grazing remain the most serious dangers (Chand Basdha ; Liese 1985; Li and Denich 2002), but bamboos are also affected by disease (Mohanan 1997; Seethalakshmi and Kumar 1998; Xu, Dai et al. 2007), insects (Haojie, Varma et al. 1998) and competition. In addition to an excessive load of climbers (Bitariho and McNeilage 2007), bamboos can succumb to storms that are predicted to become more intense with Climate Change in many regions, particularly South East Asia and the South Pacific (Gagnon, Platt et al. 2007). Nevertheless, despite a height-diameter ratio (h/d-ratio) that frequently surpasses 150, they are surprisingly wind-firm (Veblen, Schlegel et al. 1980; Stokes, Lucas et al. 2007). Timber trees become increasingly susceptible to blowdown and breakage if their h/d-ratio exceeds 75 (Mitscherlich 1978)

Vulnerability of bamboo to climate change has apparently received little attention. Habitat loss due to warmer temperature is suspected (Bitariho and McNeilage 2007) and may, therefore, present risks to the panda (Li, Krauchi et al. 2006; Yin, Xie et al. 2006). On the other hand, some bamboos have extended their range in Korea due to warming trends (Oh, Kim et al. 2004). Given IPCC's climate forecasts for the bamboo areas and the characteristics described above, temperate bamboos might suffer from heat and windstorms, and all bamboos from drought, fire and extreme cyclones. Their flowering and reproductive patterns, distribution and competitive strength could change and they might succumb to new pests, diseases and invasive plants, just like timber species. However, short rotations and more rapid stand replacement, would mitigate this risk. Ex-post analysis of risk in bamboo management, or of responses to climate change, would help adaptation and mitigation.

MONITORING BAMBOO A/R PROJECTS

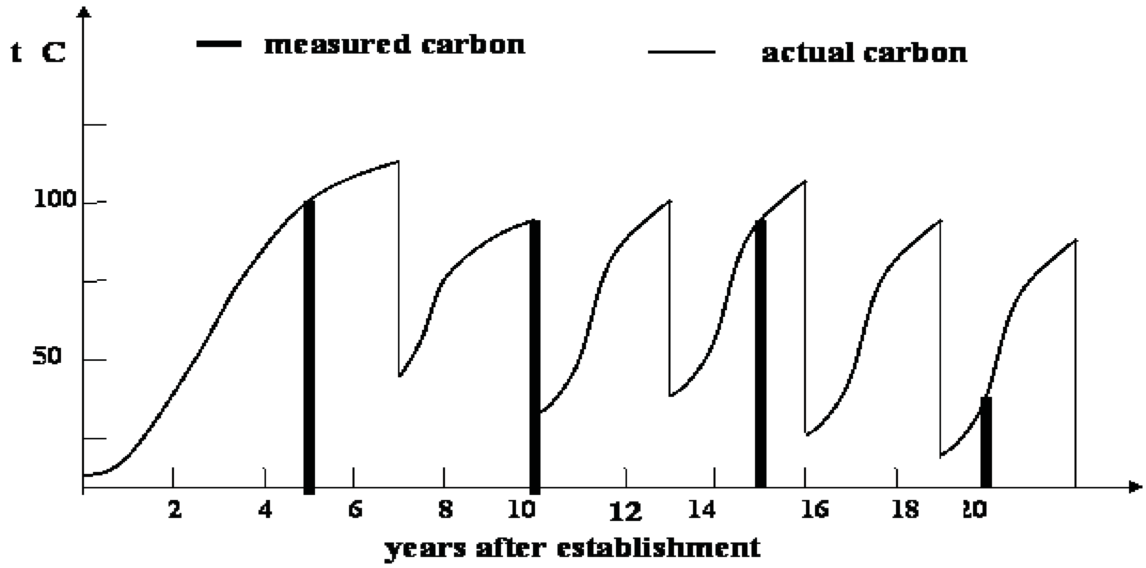
Any well-managed forest enterprise relies on periodic monitoring, assessment and planning. Essentially, the CDM's rule of monitoring in 5-year intervals merely intensifies normal forest monitoring. However, bamboo management and carbon accounting may interact.

For timber species, carbon will accrue more or less continuously up to rotation age. Stocks in bamboo stands, after culminating early, will fluctuate with harvesting and disturbance during the CRP. Timing of carbon monitoring, biomass growth, cutting cycle, and cutting intensity interact; average actual carbon stocks and average measured carbon stocks of the fixed five-year interval usually differ (Figure 7). The CDM rules do not allow deliberate synchronized monitoring to coincide with peak carbon stocks. However, choosing the time of the first monitoring, the length of the cutting cycle and the cutting intensity as independent variables in modeling can optimize joint net revenues from forest products and carbon.

A recent study on bamboo's potential role in the CDM (Widenoja 2007) described bamboo projects as a "project developers' nightmare, because project proponents would have to pioneer the first methodology". Reflecting physiological and anatomical differences, methods developed for timber trees may not apply to bamboo. Inventories of carbon stock changes under A/R and REDD will ultimately translate into currency. Therefore, they require higher accuracy and precision than country inventories for the purpose of national reporting of emissions under UNFCCC.

Monitoring A/R projects or REDD entails new and expensive measurements of carbon as an additional parameter. Lowering this hurdle would clearly facilitate bamboo A/R and REDD. Without doubt, researchers can devise efficient monitoring methods and default parameters for carbon inventories in bamboo forests. However, such studies exceed the scope of this paper. Appendix I offers an exploratory analysis of methods and carbon inventory parameters. These findings are tentative and should not replace a thorough search of the literature and further research. Preliminary results indicate, however, that current IPCC methods, default parameters and terms for emission inventories in forests do not always pertain to bamboo.

Figure 7. Carbon monitoring in bamboo with three-year cutting cycle



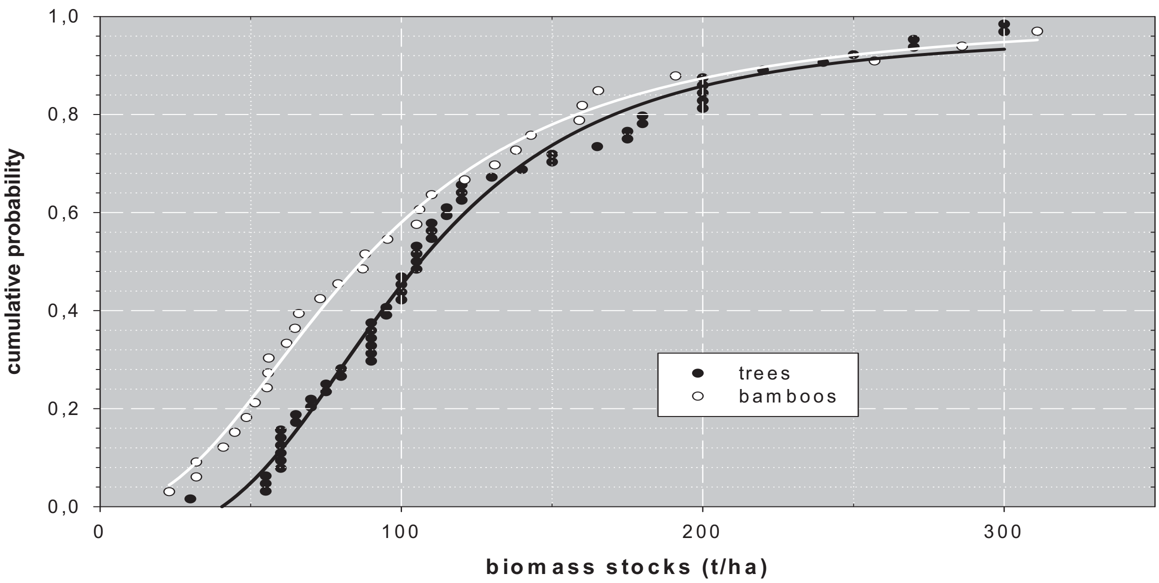
CONTRASTING BAMBOO AND TIMBER SPECIES

CARBON STOCKS

Objectively comparing average carbon storage of timber species and bamboos, for instance at the culmination of mean annual aboveground biomass growth, would necessitate site-specific species trials with replications, and measurement of all biomass components. Obviously, strict comparability is rarely given. On the other hand, merely comparing lists of published carbon stock data for both groups produces little insight (Hunter and Wu 2002; Widenoja 2007).

A pragmatic approach from Bayesian decision analysis facilitates a more meaningful comparison. Average values for biomass stocks of timber species (IPCC 2007a, table 4.8) and published biomass data for bamboos are compared graphically. Both samples may result from biased observations, varying sites, silvicultural regimes, and/or age structures. Clearly, a formal statistical test would be meaningless. However, for lack of comparable, unbiased data, the samples are accepted tentatively and arranged as subjective probability distribution functions according to the sparse data method (Anderson, Dillon et al. 1977; Snedecor and Cochran 1978), Figure 8.

Figure 8. Cumulative distribution for biomass stocks of bamboo and trees



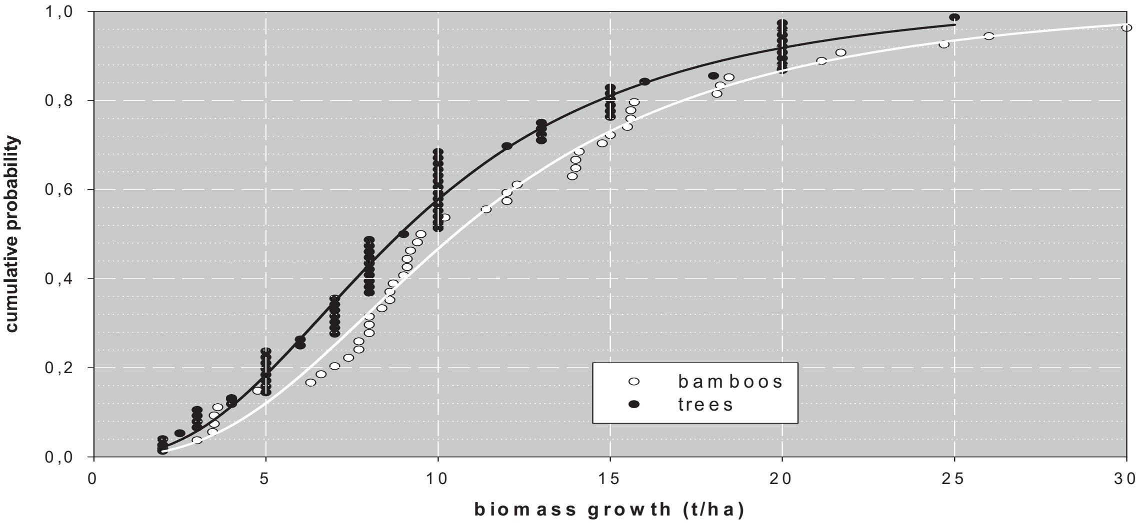
The functions reflect the probability of observing, a biomass stock below or above any arbitrarily chosen threshold for each species group. For example, the probability of observing aboveground biomass of less than 150 t/ha is about 80% for timber species and almost 90% for bamboos. Median biomass of timber species is 105 t/ha, of bamboos 87 t/ha. Overall, the distribution functions for aboveground biomass do not differ drastically, with a tendency for lower biomass stocks in bamboos. Only average biomass data for timber species were used. Maximum biomass stocks of timber trees exceed those of bamboos (Hunter and Wu 2002).

CARBON SEQUESTRATION

While most timber species need decades or centuries to reach maturity, bamboos usually mature in less than a decade. This implies high biomass growth rates. According to the literature, bamboos perform roughly equivalent to fast growing plantation species on good sites, with an increment biomass of between 5 and 12 t/ha/yr.

Average default values for aboveground biomass growth of plantation timber species (IPCC 2007a, table 4.10) and published growth rates for bamboo indicate similarity, with a trend towards higher biomass growth rates for bamboo (Figure 9).

Figure 9. Cumulative distribution for biomass growth for bamboos and trees



CARBON POOLS IN HARVESTED PRODUCTS

Harvested wood products are currently excluded from carbon accounting under the Kyoto Protocol. Countries may opt to report this carbon pool under the UNFCCC, guided by methods provided in the 2003 IPCC Good Practice Guidance (IPCC 2003). A future climate agreement might include this carbon pool as an added criterion for carbon management and species selection.

On the average and subject to further research, the myriad of bamboo products are probably less durable than wood products, e.g. bamboo products last 1-3 years in contact with the soil, and 15-20 years as building material. Under this assumption, the carbon pool in bamboo products would decline more rapidly than that of a comparable amount of wood products. However, with continuous replenishment, the size of the product pool at a point in time is a function of both product lifetime and replenishment rate (Schoene and Schulte 1999).

The pool increases linearly with the amount of products added, but less than proportionally with longer product lifetime. For example, doubling annual input of new material to a product pool will double the steady-state carbon pool. Doubling the average lifetime of products will less than double the size of the steady-state carbon pool. Therefore, a higher sustainable yield and annual bamboo harvest would compensate to some extent for shorter lifetimes of its products.

$$s = \frac{X_0}{1 - \exp^{-K}}$$

where

s = product pool at the equilibrium state;

X_0 = constant amount replenished annually;

K = decay constant for the product.

SUITABILITY FOR A/R PROJECTS

Obviously, species choice in a carbon offset project hinges on numerous factors, such as site characteristics, costs and revenues, the alternative rate of return, product markets, labor- and/or capital intensity, socio- environmental effects, risk, and chances of project registration and marketing. However, prospective carbon stocks and rates of carbon sequestration are particularly important and some generalization seems possible.

Where investment capital is limited, and moderate overall economic returns from rapid and continuous carbon sequestration are preferred, bamboos with their uneven-aged stand structure appear attractive. Growers can obtain sustained yield on even the smallest parcel of land. The maximum amount of Temporary Certified Emission Reduction (tCERs) is reached quickly; carbon adds a relatively high proportion to moderate bamboo revenues. A steady income from both sources would remain roughly constant over the project Crediting Period (CRP). After its end, the A/R project cannot be renewed. It no longer produces Certified Emission Reductions (CERs). Total revenues would drop and depend on bamboo management only.

Short-rotation timber species, producing low-value wood for pulp and paper, would roughly match this pattern. However, in contrast to uneven-aged management of bamboo, even-aged management of typical plantation timber species produces few if any returns from timber up to the final harvest. In the meantime, carbon would produce moderate but increasing revenues proportional to accumulating carbon stocks.

For sawn timber and veneer species, initial investment will typically be higher, followed by a period where sequestered carbon delivers almost all of the modest revenues. Net earnings from both carbon and timber will subsequently increase as stand growth and carbon sequestration accelerate and larger-diameter trees are harvested selectively. Assuming constant carbon prices, timber will contribute an increasing share of the combined revenues through periodic harvests of high-value saw timber and/or veneer. If the rotation exceeds the CRP, yields of high-value timber will compensate for loss of carbon revenue.

Typically, timber species will be the preferred option for large, investor- driven, industrial A/R projects with even-aged management involving many age-classes to enable sustained yield. Bamboos, on the other hand, match available resources of capital, labor, land, knowledge, and experience as well as the livelihood needs of low-income, small-scale landowners and rural communities. Properly facilitated by host countries, bamboo A/R projects could smooth the disparity between the lofty poverty reduction and development goals of the CDM and current implementation of projects in the forestry sector, Table 3.

Table 3. Bamboo attributes for climate change

Attribute	Advantage	Disadvantage
short rotation	Early returns; flexibility in land use and adaptation to climate change; lowers consequence of losing stand; smaller area needed for sustained-yield operation; fits well into crediting periods and tCER concept; fits well into small-scale CDM; low interest capital intensity; short exposure to risks;	high nutrient exports; high frequency of potential site-degrading interventions, e.g. compaction; no l-CERs
continuous yields	Continuous economic returns, employment, labor demand;	
uneven-aged management	Multitude of products; no clearcuts; less soil nutrient losses and site deterioration; lower weeding, herbicide use, establishment-stage risks;	difficult access to interior of sympodial clumps; more difficult monitoring; thinning rules;
persisting rhizomes after culm harvest	Low decline in biomass and carbon store: easy regeneration;	may impede intermittent or subsequent agricultural use
plethora of products	very high conversion efficiency, low conversion losses; flexible reaction to market fluctuations; continuous economic benefits along supply chain from cottage industry to large-scale industrial production;	
high appeal to consumers	high economic returns for bamboo products from T-shirts to medicines to floor panels;	
wood substitute	reduces demand for timber	
establishment vegetatively	Cheap, easy, independent of seed years	
labor intensive	Creates employment or self- employments; capital extensive; employment for women, youths;	sensitive to rising wages at industrial scale
light when air-dry	manual skidding and transport, animal use, no soill compaction	
possible integration into agroforestry schemes	Reduces slash and burn agriculture and/or deforestation; opportunities for climate change adaptation; synergies mitigation/adaptation	allelopathy possible
many species, world-wide distribution	Adaptation to specific sites and climate change possible; use as introduced species; overlap with CDM countries	
rapid below-ground growth	site reclamation and organic matter and carbon accumulation	possible invasiveness; slope failures on dense root mass;
C3 - plant	Increases production at higher CO_2 concentrations	More sensitive to drought than C4 plants
anatomy and physiology	Low ash-, silica- and water content as biofuel	challenging carbon monitoring; emissions of methane and NMVOC; cyanide content of shoots; mass flowering risk;

ADAPTATION AND BAMBOO

Significant climatic changes are expected for the regions where bamboo species abound as natural or introduced species (*IPCC* 2007c). Climate Change will not bypass bamboos. Main threats from Climate Change arise from fire, drought, new pests and diseases, as well as storms. Periods of gregarious flowering might change. Even if their sensitivity to Climate Change is not well explored, natural stands and plantations of bamboo might need to be managed adaptively. As opposed to timber species with slow maturation, bamboo's short rotations facilitate hedging and continuous adaptation, in response to emerging climate patterns. Systematic monitoring of bamboo will be essential and might be undertaken in the context of routine forest resource assessments, REDD or the CDM. Appendix IV offers a brief description of the concept of adaptive forest management and technical options.

Bamboos might also help societies in developing countries to adapt to climate change through the previously described environmental and socio-economic services. As wood substitutes from plantations, bamboos can reduce deforestation and degradation in natural forests. By mitigating poverty and enhancing livelihoods, they might strengthen resilience of rural societies. Integration of bamboos into settlements, croplands, agroforestry systems, and shifting cultivation patterns is an almost immediately effective option.

SUMMARY AND CONCLUSIONS

Climate Change science, UNFCCC and the Kyoto Protocol all acknowledge forests as stores, sources and sinks of carbon, as alternatives to fossil fuels and high-energy materials, but also as potential victims of climate change. Accordingly, forests play an important role in mitigation and adaptation in the current Commitment Period (CP) for achieving emission redyctions. They are likely to become much more important in the future in the context of the UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD), in a more comprehensive form of the Clean Development Mechanism (CDM) of the Kyoto Protocol, in biomass energy, and in adaptation of vulnerable human societies. Sustainable forestry, combined with Bioenergy Carbon Capture and Storage (BECS) could become a unique mitigation option, providing not only renewable energy, but also actively pumping CO_2 out of the atmosphere (Hare 2009).

Bamboos, on the other hand, have been overlooked in the current climate change regime. They are missing in the forests definitions of the Marrakech Accords (MA) and the Clean Development Mechanism (CDM). They have been disregarded in IPCC Assessment Reports, and in current IPCC guidelines for Greenhouse Gas Emission Inventories. The fact that bamboos are botanically not trees but grasses, and that they have traditionally been considered "the poor man's timber" may help explain these omissions. Other global forest definitions, such as FAO's, include bamboos.

This study provides arguments for considering bamboos as forests under the CDM, under REDD and in National Communications. The Executive Board of the CDM has recently concurred to allow bamboo in A/R projects, but has left the final decision to individual countries. Up to now, only two Designated National Authorities (DNA's) have accepted bamboos. These decisions apply to the CDM only.

Bamboo distribution overlaps with prominent CDM host countries in Asia and Latin America, which can also build on considerable experience with bamboo. In contrast, most potential host nations in Africa lack practical exposure to the CDM, but many are at least familiar with management of natural and planted bamboo. Here, bamboo afforestation/reforestation projects might eventually spawn a pro-active administrative structure and CDM projects in other sectors.

Not considering tree-like bamboo stands as forests in the REDD process, neglects significant carbon stores, highly effective carbon sinks, and proven pillars of rural livelihoods. It invites destruction of bamboo forests. New bamboo plantations may curb the pressure for deforestation by serving as wood substitutes, as woody components of permanent agroforesry systems, and as a means to curb the spread of slash-and-burn agriculture. Thus, incentives for bamboo plantations could become an important component of a REDD strategy.

The current CDM has essentially bypassed the forest sector, which, up to now, harbors only eight CDM projects from over 1800 worldwide. In spite of its explicit goal, the CDM has largely failed to reduce poverty, improve livelihoods or foster development in rural neighborhoods. Sequestering carbon in bamboo A/R projects might correct this deficit by circumventing many of the current impediments for forestry projects. Bamboos combine many attributes that predestine them for a sizeable niche in the CDM, particularly in Small-Scale Afforestation/Reforestation Projects.

Advancing climate change will not spare bamboo. Northerly range shifts have already occurred. Missing are more reliable forecasts of how bamboos will cope with projected extreme temperatures, droughts, floods, late-or early frosts, or more intense storms. In any case, short growing cycles and a rich palette of species should allow for hedging and flexibility in adapting stands to climatic changes.

Their characteristics also predispose bamboos for a prime role in adapting human societies to climate change. Reducing poverty and boosting rural livelihoods are prime measures for adaptation. Moreover, bamboos may be integrated rapidly into many agroforestry, shifting cultivation and urban systems. Beneficial environmental effects of bamboo, that range from reclamation of severely degraded sites to providing shelter during floods, tsunamis and earthquakes may foster project developments. However, not all environmental effects of bamboo are beneficial.

Moreover, bamboo projects in the CDM and REDD face their own, specific hurdles. In particular, sampling designs, carbon assessment methods and default parameters devised for timber trees rarely apply to bamboo. However, many advantages of bamboos, the current extent of bamboo forests, and a much larger area of potential distribution, would justify an amending the IPCC guidelines and/or adding specific methodology tools for bamboo. Regional studies on bamboo carbon assessment, perhaps linked to regional bamboo pilot projects, could lower these hurdles, support bamboo as the poor man's timber, and establish a sizeable niche for bamboo. The poor man's timber could become the poor people's carbon sink.

APPENDIX I

MONITORING CARBON IN BAMBOO

Terminology

The most recent global bamboo resources assessment (Lobovikov, Paudel et al. 2007, p.26; p.9), illustrates that inventory techniques for bamboo are at a rudimentary state. Most countries with bamboo resources were able to furnish at least basic bamboo data, such as area, ownership structure and forest characteristics. Only half were able to quantify bamboo growing stock; and few could report bamboo biomass. China alone provided carbon stocks. Besides the forest sector's past neglect of the "poor man's timber", lack of appropriate definitions and efficient assessment methods is probably the main reason for scarce and unreliable carbon data.

The current definition of bamboo growing stock is ambiguous (Lobovikov, Paudel et al. 2007, p.47). It is unclear if only the culm, or also leaves, sheaths and branches are included, and if green weight in the forest, air-dry weight or oven-dry weight is employed. Stump height and top diameters must be defined. For consistency, terminology from the 2006 Guidelines for forest GHG inventories should be applied to bamboo, Table 4.

Table 4. Terminology for bamboo stocks and changes

Component	Stock	Gain	Loss from harvest
Merchantable volume	growing stock	net annual increment	removals
Biomass of the merchantable volume	growing stock biomass	increment biomass	removals biomass
Aboveground biomass	aboveground biomass	belowground biomass growth	aboveground biomass removals
Belowground biomass	total biomass	belowground biomass growth	belowground biomass removals
Total biomass	total biomass	total biomass growth	total biomass removals
Carbon	carbon in (any of the components above), soils organic matter, litter and deadwood		

Current mensuration methods

Simple field inventories tally the number of culms or clumps per ha. Conversion coefficients then apply species-specific average numbers of culms per tonne to obtain the weight of the growing stock per ha (Lobovikov, Paudel et al. 2007). A variation predicts total culm weight from clump diameter (Krishnankutty and Chundamannil 2005). However, culm dimensions and air dry weights for bamboo species vary considerably by age, silvicultural treatment, and site. For example, a tonne of Bambusa tulda may contain between 30 and 200 air-dry culms; Dendrocalamus strictus, Melocanna bambusoides and Dendrocalamus longispathus may contain 400-700, 350-500 and 50-150 culms per tonne, respectively (Liese 1985).

A growing stock and biomass inventory for Indian forests demonstrates an alternative inventory method (Chhabra, Palria et al. 2002). Here, growing stock volume of bamboo inventoried in the forest is converted to biomass by the formula:

$$AGB = GSVD * DEN * (1-MC) * BEF$$

where:

AGB is aboveground biomass

GSVD is growing stock in $m^3\ ha^{-1}$

DEN is the apparent green density of bamboo wood including cavity volume (here 0.575)

MC is moisture content (here 0.89)

BEF is the biomass expansion factor, here 1.27.

BEF is a multiplication factor that expands the dry-weight of growing stock biomass, increment biomass, or biomass of wood-removal to account for non-merchantable or non-commercial biomass components, such as stumps, branches, twigs, foliage, and, sometimes, non-commercial trees. Biomass expansion factors usually differ for growing stock (BEFS), net annual increment (BEFI), and wood- and fuelwood removals (BEFR). As used here, biomass expansion factors account for aboveground components only.

A "root/shoot ratio" (here 0.528) was employed to account for belowground biomass. The method presumes volume measurement of culms, known apparent green densities, average water content of culms, an accurate biomass expansion factor, and known carbon fraction of bamboo biomass. These parameters are often not known, may vary by species, site, age, weather conditions, season of the year, and would need to be established by additional studies for wider applicability.

A third method, laborious and usually employed in research, establishes allometric equations for broader applicability. The method separates culms, branches and leaves, rhizomes and roots by destructive sampling. Fresh weights for each compartment of the plant are recorded in the field. Culms are either randomly selected or sorted by age.

The procedure excavates rhizomes, as well as coarse and fine roots, and passes them through a series of sieves of different mesh size. Alternatively, estimating belowground biomass necessitates expensive, direct observation via samples from various soil depths that must be repeated at the same depth and during the same, appropriate time of the year.

After washing and oven-drying sub-samples, ratios between dry and fresh weights are applied to fresh-weights. Diameter at breast height (DBH) or at other internodes, and culm heights are measured. A regression fits a mathematical model to the data, where diameter and sometimes height are the independent, and culm dry-weight, dry-weights of other compartments and/or total aboveground biomass are the dependent variables. Equations for biomass components must be adjusted, so that the sum of the regression estimates is compatible with the function for total aboveground biomass. For some species, such allometric equations are available, but goodness of fit should be ascertained locally (Veblen, Schlegel et al. 1980; Christanty, Mailly et al. 1996; Mailly, Christanty et al. 1997; Pattanaik, Pathak et al. 2004; Castaneda-Mendoza, Vargas-Hernandez et al. 2005; Oli 2005).

For physiological reasons described above, allometric functions will usually differ by age or stage of maturity (Castaneda-Mendoza, Vargas-Hernandez et al. 2005). Therefore, biomass stock change cannot be assessed by considering only culms that emerge over a five-year monitoring interval. Older culms contribute to biomass growth through increases in specific gravity or belated branching. Therefore, separate allometric equations have to be established for culms of different ages, or culm age must be included as a continuous or dummy variable in regressions.

This allometric method, while potentially very accurate, involves considerable effort. Therefore, coordinated regional research efforts should establish models and apply them regionally. Obviously, a complement to the IPCC Guidelines specifically for bamboo, including definitions, mensurational and sampling methods, as well as default values would be highly useful for facilitating bamboo A/R projects, REDD, and country reporting under UNFCCC.

Current IPCC Guidelines

Countries usually choose one of the following two methods to assess carbon removals or losses in forests (IPCC 2003):

Method 1, the default or gain-loss method, assesses periodic changes in carbon stocks as the difference between annual increase in carbon stocks due to biomass growth and annual decreases of carbon stocks due to biomass losses, e.g. by disturbance. It presumes only one inventory at the beginning or the end of the period. The method seems ill suited for bamboo, as aboveground biomass growth is highly uncertain, varies periodically, and is dependent on harvesting of culms.

Method 2, the stock change method, presumes periodic initial and final inventories. It does not require projections and removal data.

Carbon stocks measurement uses the equation:

$$C_t = V*D*BEF*(1+R)*CF$$

Where:

C_t=total carbon in biomass at time t_1, t_2 in tonne C

V= growing stock (merchantable volume) in m^3

D= basic density in t dr. wt./m^3

BEF= Biomass Expansion Factor for expansion of the oven-dry-weight of the merchantable volume of the growing stock to above-ground biomass, dimensionless

R= root/shoot ratio; ratio of dry-weight of the below-ground biomass to above-ground biomass, dimensionless

CF= percentage carbon in dry matter

The 2006 IPCC Guidelines (IPCC 2007a) also allow allometric equations for individual sample trees, or biomass functions that convert stand growing stocks directly to total biomass without resorting to expansion factors.

These Guidelines also introduce a Biomass Conversion and Expansion Factor (BCEF), which combines wood basic density and BEF in one factor that directly converts measured growing stock volume of forests to biomass dry-weight. Usually, bamboo inventories do not measure volume, but weight. Moreover, volume of bamboo culms fluctuates appreciably with their water content. Depending on season, culm age, and site, moisture content can vary by 100% and more. Therefore, shrinking and swelling may change culm diameters by more than 10% (Liese 1985). Applying BEFs to measured dry-weights appears more reliable than converting uncertain culm volumes to aboveground biomass via BCEFs.

For small bamboo species, an optimal carbon inventory method most likely involves direct weighing. For taller species, allometric biomass equations, which are directly applicable to sample trees or stands, should replace expansion factors. Either method must allow for variable culm moisture contents.

For trees, default or specific root/shoot ratios convert aboveground to total biomass. For bamboo, the root/shoot ratio is a misnomer, as rhizomes are shoots. The term "belowground/aboveground ratio" (B/A-ratio) appears more suitable.

Parameters for carbon measurement

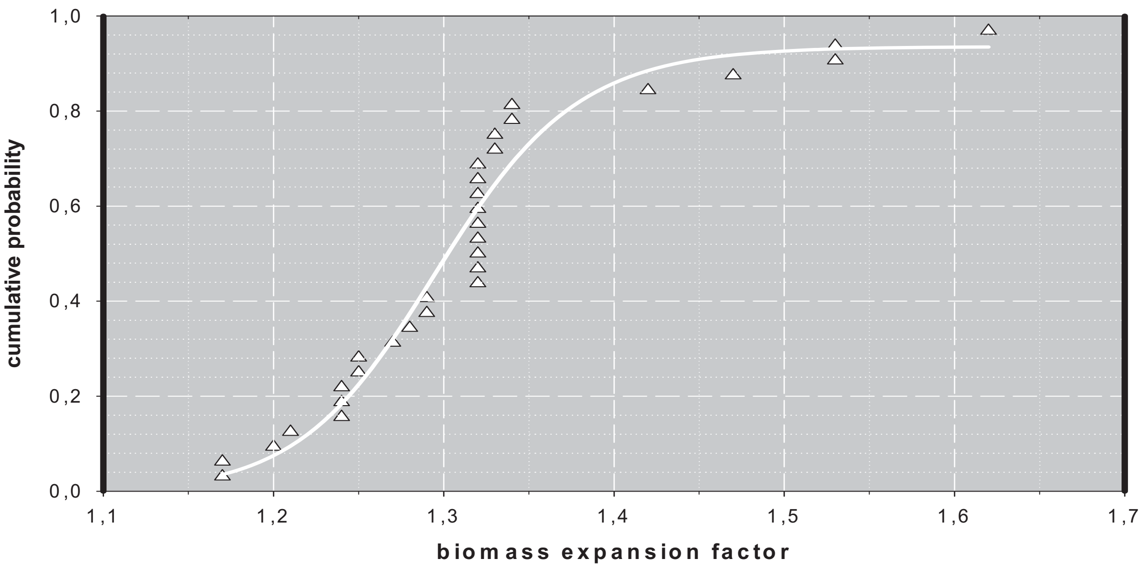
Specific gravities

Densities of bamboo culms vary between 0.5 and 0.9 g/cm^3 (Liese 1985; Seethalakshmi and Kumar 1998; Li, Shupe et al. 2007). Air-dry densities range between 0.43-0.82, including 7-19% water (Seethalakshmi and Kumar 1998; Scurlock, Dayton et al. 2000). For Guada angustifolia, apparent green density, including culm cavity, is 0.48 g/cm^3, whereas oven-dry density of the culm biomass is 1.03 g/cm^3 (Kleinn and Morales-Hidalgo 2006).

Biomass Expansion Factors

The distribution function of BEFs, established from a sample of published studies by the sparse data method (Anderson, Dillon et al. 1977; Snedecor and Cochran 1978) has a range from 1.15 to 1.6 and a median of 1.3, coinciding with the mean biomass expansion factors for timber species (IPCC 2003). However, BEFs for trees comprises much higher values (Figure 10). The range is 1.15 to 4.2 for temperate and boreal trees, and 2 to 9 for tropical trees.

Figure 10. Biomass Expansion Factors of bamboos



Belowground/aboveground ratio

Bamboos invest a large proportion of assimilates below-ground (Hunter and Wu 2002). Since belowground biomass includes both roots and rhizomes, the distribution function for the B/A- ratio with a median of 0.41 exceeds root/shoot ratios for timber species (IPCC 2003), Figure 11.

Biomass/basal area-ratio

Basal area of bamboos, that is, the sum per hectare of all culm cross sections at breast height, usually expressed as m^2/ha, resembles that in timber stands. Available data indicate a close correlation between aboveground dry-weight (and carbon) and stand basal area, regardless of species and height (Figure 12). In timber inventories, volume-basal-area ratios (VBAR-ratios) or form-heights(Kramer and Akca 1982) simplify growing stock measurements. Since basal area is easily measured, such ratios between weight or carbon and basal area might also facilitate bamboo biomass and carbon assessments. The relationship might be further explored.

Figure 11. Aboveground/belowground-ratio of bamboos

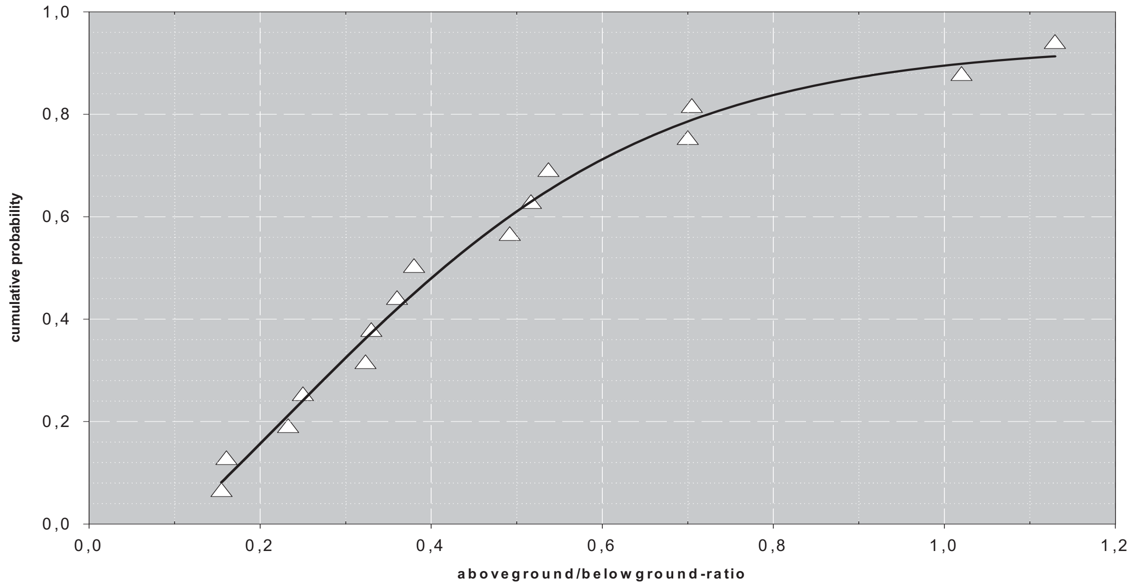
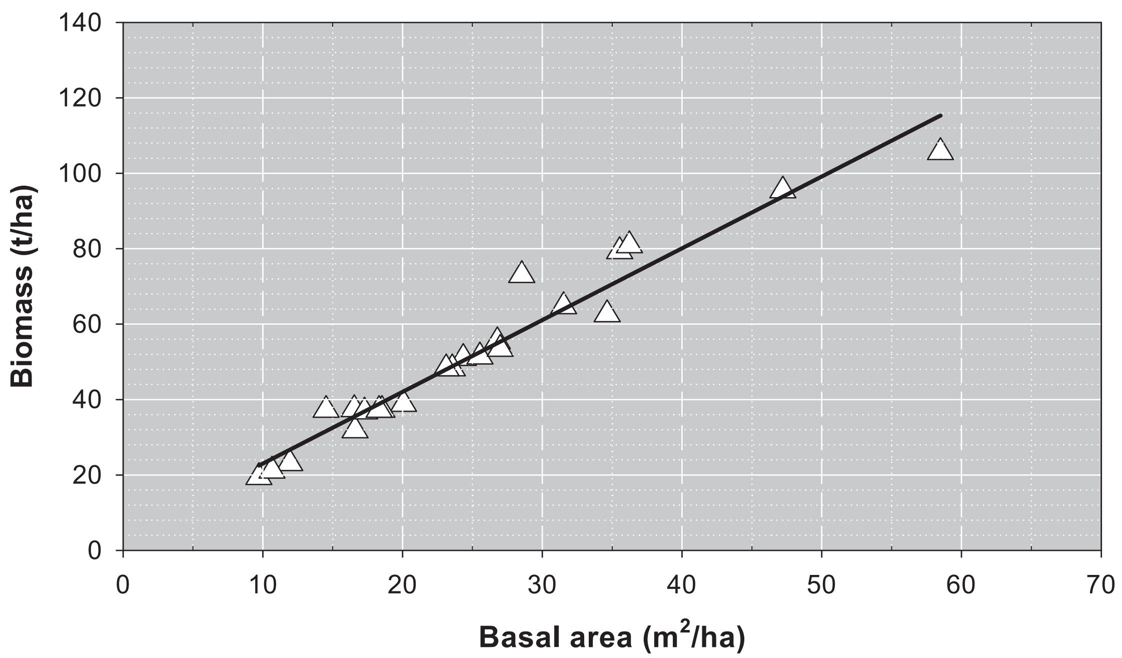


Figure 12. Biomass of bamboos as a function of basal area



APPENDIX II

PRIORITY SPECIES OF BAMBOO

Most important species

Bambusa balcooa Roxb.

B. bambos (L.) Voss

B. blumeana J A and J H Schultes

B. polymorpha Munro

B. textilis McClure

B. tulda Roxb.

B. vulgaris Schrad. ex Wend1

Cephalostachyum pergracile Munro

Dendrocalamus asper (Schultes f.) Backer ex Heyne

D. giganteus Wallich ex Munro *D. latiflorus* Munro

D. strictus (Roxb.) Nees: *Gigantochloa apus* J A and J.H. Schultes

G. levis (Blanco) Merrill

G. pseudoarundinacea (Steud.) Widjaja

Guadua angustifolia Kunth

Melocanna baccifera (Roxb.) Kurz

Ochlandra Thw. (Spp.) : *Phyllostachys pubescens* Maze1 ex H. de Leh : *P. bambusoides* Sieb. and Zucc P. edulis Makino

Thyrsostachys siamensis (Kurz) Gamble:

A further 18 taxa were noted to be important:

Arundinaria spp

Bambusa atra Lindl. (Neololeba atra (Linn) Widjaja)

B. heterostachya (Munro) Holtum

B. nutans Wall. ex Munro

B. oldhamii Munro

B. pervaria bil is McClure

Lingnania chungii McClure

Dendrocalamus brandisii (Munro) Kurz

D. hamiltonii Nees

D. hookeri Munro

D. membranaceus Munro

Gigantochloa albociliata (Munro) Kurz

G. atroviolacea Widjaja

G. balui Wong

G. asskarliana (Kurz) Back. ex Heyne

Oxytenanthera spp. Munro

Phyllostachys glauca McClure

Schizostachyum spp. Nees

APPENDIX III

BAMBOO GLOSSARY

cortex: Outer part of a culm (also called bamboo green or rind) or rhizome, between epidermis and ground tissue.

culm: The aerial axis emerging from buds of the subterranean system, divided into nodes and internodes.

culm sheath: The tubular leaf, inserted at a node and covering part of the culm.

diaphragm: A transversal tissue partition of the culm at the node, containing intensive interconnections of vessels and sieve tubes.

epidermis: The outermost layer of a culm or rhizome, often with thickened and cutinized outer wall.

fibre: Long cells with lignified walls, generally dead, providing mechanical support for the culm as fibre sheath or fibre bundle.

fibre bundle: A group of fibres that forms a part of the vascular bundle, and isolated by parenchyma from the metaxylem and phloem.

immature: Referring to young culms in which the lignification that strengthens the tissue is not yet complete.

internode: The part of the culm or rhizome that lies between two nodes.

lacuna: Inner space of a hollow culm; syn. pith cavity.

leptomorph: Slender, elongated type of rhizome with buds at the nodes, resulting in single-stemmed culms; syn. monopodial.

lignification: Formation of a polymer within the cell wall that provides strength to the culm.

maturation: The process of lignification of the cell wall that strengthens the culm.

moisture content: The weight of water in the culm, expressed as a percentage of its oven-dry weight.

monopodial: See leptomorph.

neck: The constricted basal part of the segmented axes of a bamboo plant.

node: A segmentation of the culm or rhizome, from where branches or roots originate. At the node, a diaphragm divides the culm.

pachymorph: A short, thick rhizome proper, typical of clump-forming bamboos; syn. sympodial.

parenchyma: Brick-shaped, generally alive cells with simple pits that store and distribute food materials.

rhizome: The segmented, complex, subterranean stem system (the "root stock" of a bamboo plant; present in two basic types —monopodial (leptomorph) and sympodial (pachymorph).

sclerenchyma: A tissue composed of sclerenchyma cells. These are variable in form and size, often with thick, lignified secondary walls.

secondary wall: Lamellae laid down on top of the primary wall during the differentiation and further ageing of a cell,

sheath scar: The mark left on the culm after the abscission of a culm sheath.

silica cell: An epidermal, short cell filled by a single silica body.

stomata: Cell complexes in the epidermis that facilitate air exchange, such as in respiration.

sympodial: See pachymorph.

tabashir: The siliceous deposit found in the lacuna of certain sympodial bamboo species.

vessel: Large cells arranged in axial series for water conduction.

Note: A Climate Change glossary is available at the IPCC website (IPCC 2009).

APPENDIX IV

ADAPTIVE FOREST MANAGEMENT

Despite uncertain, but altering future environmental conditions, forest managers must make decisions and implement plans, which are based on assumptions of longer time spans than in other forms of natural resource management like agriculture or fishery (Spittlehouse, Pollard et al. 1989; Spittlehouse and Stewart 2003). For example, the decision on which tree specie to select for a plantation or on silvicultural interventions could set the path of land use for decades or centuries. Adaptive forest management is a suitable approach to proceed conscientiously in the face of such uncertainty. The approach is one that "…provides a sound alternative to either "charging ahead blindly" or "being paralyzed by indecision", both of which can foreclose management options, and have social, economic and ecological impacts (Nyberg 1999).

The key characteristics of adaptive management include:

- Acknowledging uncertainty about what policy or practice is "best" for the particular management issue;
- Thoughtfully selecting policies or practices to be applied;
- Carefully implementing a plan of action designed to reveal the critical knowledge;
- Monitoring key response indicators;
- Analyzing the outcome in consideration of the original objectives; and
- Incorporating the results into future decisions.

An essential element of adaptive forest management is that knowledge generated by learning is reintegrated into the project/working cycle and hence leads to adjusting and improving silvicultural techniques and the forest management approach.

Table 5. Silvicultural and management methods for adapting bamboo forests

Phase	Measure
Regeneration	adjust silvicultural system and/or regeneration technique
	prefer mixed stands
	match species and provenance to present and future site and climate
	consider proven introduced species
	adapt natural regeneration to changing reproduction and competition patterns
	rehabilitate degraded and eliminate off-site stands
	consider nurse trees
	consider artificial shading in planting dry, exposed sites
	adjust planting densities
	monitor competing vegetation
	add nutrients likely to become deficient
	under-plant high risk stands
	treat for wind resistance starting systematically from establishment
	reduce excessive game, rodent populations
tending of stands	adjust intensity and frequency of precommercial thinnings and stocking control
	adjust stand structure and composition
	phase out off-site stands
	enhance monitoring for pathogens and insects
harvesting	avoid large clearcuts, edge effects, fragmentation
	adjust harvest method and equipment, reduce impact of skidding
	consider converting to uneven-aged stands
protecting forests	intensify monitoring of risk and damage
	eliminate added stresses (acid rain, game)
	adjust fire management; use fire-smart landscapes
	protect rare habitats, species, and genetic stocks
management, planning, and administration	raise awareness of and information for top and field staff, owners
	educate extension foresters
	rewrite silvicultural and management guidelines
	intensify or update site classification and mapping
	provide adequate human resources; management and labour intensity likely to increase
	plan and train for calamities and timber salvage, sales pools
	integrate climate change into management plans
	reconsider rotations and allowable cut
	reconsider species choice and introduced species
	update yield tables
	carry out professional national and local vulnerability analysis
	prioritize no-regret options
	practice adaptive forest management
	intensify and adapt variables in periodic national forest assesements
	monitor for climate change impacts in protected areas

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