# Section III

# Trees as providers of environmental services in multifunctional landscapes are vulnerable to climate change

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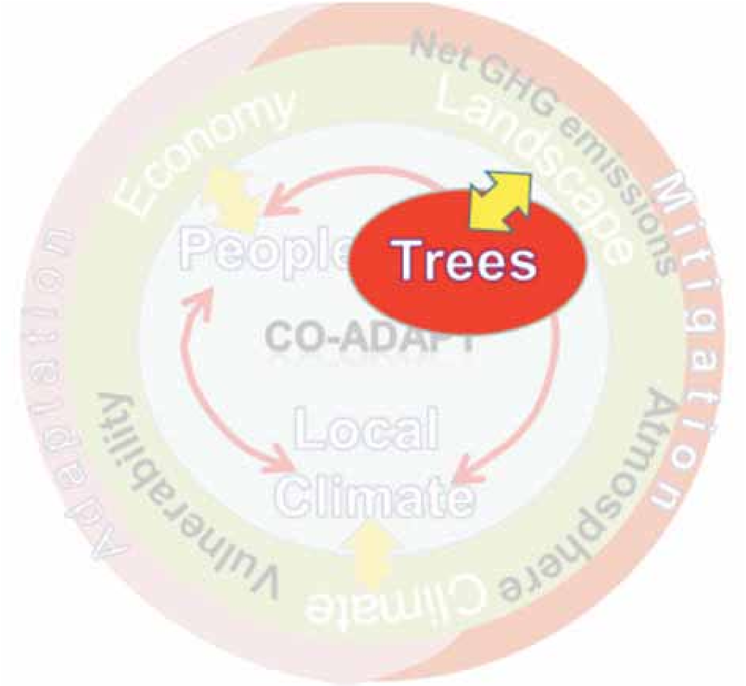
In this section we provide a more in-depth look at the role trees play in the provision of goods and services in multifunctional landscapes. Tree growth is, however, vulnerable to climate variability, depending on the physiological properties of the tree and characteristics of the site. A further quantification of climate variability and climate change is needed to advise on what types of trees can be grown where, to be ready for the likely local climate-change during their lifetime. This leads to a discussion of the two-way relationship between climate change adaptation and rewards for environmental services in multifunctional landscapes as a way to reduce vulnerability to climate change.



## E. Trees as providers of environmental services in multifunctional landscapes

There are several main points in this chapter.

- Farmers plant trees primarily for their products and see environmental services as a ‘co-benefit’
- Trade-offs between the provision of goods and environmental services need to be acknowledged and, where possible, quantified

- Species' diversity and genetic variation support ecosystem functions
- Domestication for value chains can support tree diversity
- Challenges exist in realising the benefits trees can provide: as germplasm exchange is restricted; the harvesting of trees on farm faces rules designed for protecting forests; and economy-of-scale effects disadvantage smallholders

## Trees for goods and services

Trees provide important environmental services in a wide range of forest and farm landscapes. These services include soil, spring, stream and watershed protection, soil fertility replenishment, biodiversity conservation, storing of carbon, and cultural values and aesthetic qualities, among other functions. For example, trees in streambeds slow water flows, reduce 'flash floods' downstream, and may enhance the functioning of local floodplains for water and sediment retention; nitrogen fixation by perennial legumes fertilises soil; 'safety-net' roots below the main crop root zone can intercept nutrients otherwise leaching out of the system; while deep roots improve soil structure and allow 'mining' of nutrients well below the soil surface.

It is estimated that, worldwide, approximately 560 million people live in agricultural ecosystems with more than 10% tree cover (Figure D.4, Zomer et al. 2009). When an active tree retention and/or planting culture exists in such communities, hundreds of tree species can be found in agricultural landscapes that form important reservoirs of biodiversity. Perceptions of their influence on water flows vary with context and ownership of the trees. The same farmland trees also play a role in promoting forest integrity under climate change. This is because they can help maintain the connectivity between the natural forest fragments that remain in the landscape, thereby enhancing gene flows and hence the ability of wild tree stands to adapt to environmental alterations. How effective farmland trees are in this regard depends on the particular locations, overall census numbers and sources of specific species in the agricultural landscape. Common trees that are more evenly dispersed will be more effective in ensuring connectivity.

## Farmers plant trees for their products

Although trees provide valuable environmental services, these functions are not generally the primary reason why farmers retain, manage and/or plant them. Rather, the impetus for cultivation is the value of the other products trees can provide, such as timber, food, medicines and energy, products with immediate and clearly apparent benefits to farmers' livelihoods. A wide diversity of several thousand trees species are cultivated for such products, as illustrated by the World Agroforestry Centre's Agroforestree Database (www.worldagroforestry.org), which lists the roles of many of the trees commonly planted or retained by smallholders.

Many species are grown by farmers for a number of different uses and the particular use depends on specific household needs and the availability of markets for particular products. This in turn determines the specific traits needed in planting material and the particular ways in which trees are managed on farms. Rarely will a single tree 'ideotype'[16] be available that fulfils a broad range of functions of a tree optimally, because such combinations of traits simply do not exist in nature and most trees are semi-domesticated at best. Unfortunately, in most developing countries, there are very few concerted efforts on tree improvement. This highlights the need for attention on selection and breeding that may result in significant productivity gains for specific functions.

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[16] The idealised appearance of a plant variety

## Trade-offs between goods and environmental services

Often, trade-offs exist between the goods trees provide and the environmental services that they bring. For example, fast-growing species such as eucalypts can produce firewood and/or valuable timber quickly, but their highly competitive use of water may prevent other species growing with them, leading to monoculture and low biodiversity value (see Intermezzo 7). In addition, the highly combustible nature of some fast-growing timbers can lead to fire and environmental damage, while allelopathic effects can also prevent other trees and crops from growing with them. Competition for water, nutrients and light between trees and crops in agroforestry systems still remain an important area of study to maximise the benefits accrued from such systems, hence, management options and studies of the right trees for the right places are critical.

Figure E.1. Trees for products (goods) and environmental services

## The role of species' diversity and genetic variation in ecosystem function

Species' diversity can play a fundamental role in maintaining and enhancing the productivity and resilience of agroforestry ecosystems in the face of environmental change. Diversification with agroforestry species can increase the expected income and hedge, for example, against catastrophic disease attacks on particular species. The extent to which diversification is beneficial depends on how different production activities complement each other. Interventions should be more concerned with maximising the functional diversity present in farming landscapes rather than simply increasing the number of tree species found in them. Since a range of local and exotic trees and crops can improve resilience to change, promoting diverse smallholder agroforestry systems is seen as a key means of 'climate-smart' development (World Bank 2009).

Genetic variation within tree species also has a role in determining how well ecosystems function. Intra-specific diversity provides the capacity to adapt to changing environments and prevents inbreeding depression associated with small population sizes. The well-documented negative effects of inbreeding in trees include low seedling vigour, poor growth form and high risks of population and/or species extinction: both productivity and conservation concerns for landscapes as a whole therefore follow. Maintaining high genetic variation in tree species is an important concern under climate change, especially as anthropogenic warming may negatively affect the pollinators that are responsible for allowing the mating between trees that maintain genetic diversity in agricultural landscapes.

## Domestication for value chains can support tree diversity

Tree domestication and diversification tends to focus on bringing useful and profitable tree species into cultivation. Within the context of climate change, this can mean exploring the new market opportunities that global warming presents. The cultivation of biofuel trees to mitigate climate change is one such opportunity (FAO 2008). Candidate species include the small tree *Jatropha curcas* (jatropha), from which biodiesel can be extracted from seed. This tree originated in Latin America, but has been planted as a medicinal tree for many centuries. The sudden increase in interest in this biofuel source has not been matched by appropriate tree germplasm and yields have remained below expectation. Realising greater mitigation benefits and higher revenues for farmers will require coordinated international exchange of higher-performing germplasm and the same can be expected for other ‘bioenergy’ trees like *Thevetia peruviana* (yellow oleander) and *Croton megalocarpus*. Climate change challenges of human disease and malnutrition, while clearly unwelcome, can provide further market opportunities for smallholders. This will be the case if farmers are able to grow medicinal trees such as *Warburgis ugandensis* and *Azadirachta indica* to treat increased disease incidence and also cultivate appropriate fruit trees to enhance consumption of nutritious foods, thereby combating micronutrient deficiencies in affected areas. Planting of these trees can be motivated by cultural factors and hence contribute to a realisation of cultural ecosystem services.

## Challenges in realising benefits

More efficient ways to get planting material to farmers—appropriately adapted and well-suited for function–is the key in responding to the challenge of climate change. Unless germplasm delivery systems are improved from their current poor performance, farmers will be unwilling to grow new

## Intermezzo 9.

### The eucalyptus debate on tree water use

Eucalyptus is a fast-growing tree and is popular as a cash crop with many smallholders in East Africa. The dilemma over the use of eucalyptus for social, economic and environmental purposes is a matter of great concern in the region (Ong 2003). On the one hand, it is highly productive with a high value in local markets. It grows fast and is resilient in diverse agro-ecological zones. Eucalyptus has multiple uses providing both goods and services, for example, timber, fuel and medicinal products such as eucalyptus essential oil. On the other hand, there are public concerns that widespread planting of eucalyptus might deplete water resources (Figure E.2), reduce stream flow and, in some instances, lead to the drying of rivers owing to high water consumption (Smettem and Harper 2009). Eucalyptus trees also compete with crops for water and nutrients and may inhibit the germination and growth of certain crops (Jagger and Pender 2003). Other concerns include reduction in biodiversity and increased flooding through modified soil conditions. In addition, there is slow litter decomposition, hence, failure to produce humus, reduced penetration of water to the soil, and occurrence of pests, for example, Blue Gum Chalcid in Kenya.

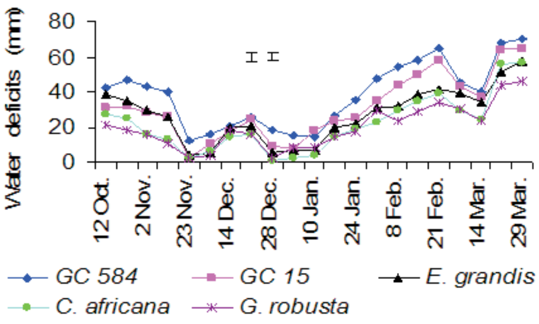


Figure E.2. Time course of water deficits of three Eucalyptus clones—Cordia africana and Grevillea robusta—between October 2005 and March 2006 in semi-arid (Thika) Kenya. Source: Shem et al. 2009

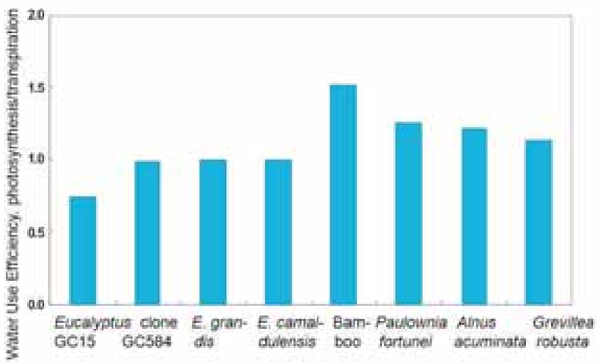


Figure E.3. Water-use efficiency (WUE) of six months-old potted seedlings from different tree species grown in Juja, Kenya. Source: Muthuri et al. 2008

In Kenya and South Africa, the introduction of hybrid or cloned eucalypts with even faster growth rates has raised new concerns. Therefore, there is an urgent need to critically assess how hard the evidence is, particularly with regard to water use. Preliminary results from studies of six months-old seedlings of different tree species, including eucalyptus, (Figure E.3) indicated that eucalyptus had a lower but insignificantly different water-use efficiency (WUE), that is, the ratio of water used per dry matter produced, compared to the other species under study. Similar findings were reported in South Africa (Dye and Gush 2008), where the WUE of eucalyptus plantations were similar to the indigenous species but the sap flow of the latter was relatively low.

These studies raise the issue of trade-offs between eucalyptus' water use and biomass and where in the landscape to plant it. The South African study recommended that 'indigenous species' would have a low impact on catchments' water yields. This has resulted in the mass removal of eucalyptus trees from water catchments. The same trend is happening in Kenya where there is a directive to cut down eucalypts in the riparian zone in order to increase stream flow. Ecologically speaking, the presumed difference between 'indigenous' and 'exotic' depends on the practice of introducing fast-growing exotics rather than slow-growing ones; growth rate and associated water use is the issue, not the biogeographic origin of a tree.

The sharing of scientific information and perceptions of various stakeholders is critical for the wise use of a potentially useful species in a region which has undergone a dramatic decline in forest cover and is facing a growing deficit in wood energy and production. Research on alternative trees with comparative growth rates to eucalyptus but more conservative water use is critical in view of climate change (Ong et al. 2006).

species to service new markets or will simply be unable to do so (Graudal and Lillesø 2007). Lack of experience and clarity, at least in the public domain, on the introduction and implications of newly introduced tree species like *Prosopis juliflora* could work against the introduction of high-quality germplasm. In developing any new market, the danger is that this will be coupled with over-exploitation of existing resources, agricultural intensification and a tendency to monoculture, which may in turn decrease the diversity and, hence, resilience of landscapes. In other words, when developing new markets to combat the effects of climate change, the result may paradoxically be that agricultural landscapes end up being less adaptable to environmental alterations. This is unless appropriate actions are taken to more effectively combine livelihoods' development with environmental concerns.

Finally, much remains unknown about how the environmental services realised by trees are themselves dependent on climate. The impacts of climate change on most trees of interest to smallholders are little researched, including issues such as how change will influence above- and belowground growth, affect the ability to sequester carbon, change phenology (for example, leaf fall, flowering, fruiting) and determine persistence. The impact of climate on these factors will determine the environmental benefits that can be realised through tree cultivation in the future.

## Intermezzo 10.

### Shade, litter, nematodes, earthworms, termites and companion trees in coffee agroforestry in Indonesia relation to climate resilience

Coffee agroforestry systems are intermediate between forest and monoculture coffee in many aspects of above- and belowground biodiversity and related functions. For the farmer, however, the balance of positive and negative aspects of diversity needs to be understood in relation to key processes such as nutrient and water uptake, slope and topsoil integrity and harvestable yield. Climate variability affects water availability, modulated by the pattern of infiltration and water-holding capacity of the soil, but also through pest and disease relationships that influence root functions in water uptake. In the Way Besai catchment (Sumberjaya, Lampung, Indonesia) that has seen a rapid transformation towards coffee in the past three decades, researchers surveyed earthworm, nematode and termite diversity profiles of forest, coffee agroforestry, simple shade-tree plus coffee mixtures, and coffee monocultures. The soil-fauna studies were combined with measurement of soil macroporosity, surface runoff and coffee yields. Four relatively large-bodied native earthworms were lost upon forest conversion, with six exotic and smaller-bodied worms replacing them. The nematode fauna shifted towards plant-parasitic genera, especially where a grass/weed understory was present. Shade trees depress ground vegetation through litter, reducing plant parasitic nematodes, but enhancing earthworms. *Gliricidia sepium*, a favourite nitrogen-fixing companion tree of coffee, is toxic for earthworms as well as plant parasitic nematodes, while banana stimulates the nematodes and provides direct yields to the farmer. Termites can shift from beneficial to pest status depending on the availability of woody debris in the system. Overall, the multispecies coffee agroforestry systems are more robust to climate variability, partially through these biotic interactions with soil fauna. Farmer knowledge tends to focus on what is visible aboveground and rationalises the benefits and negative impacts of various companion trees in terms of 'hot' or 'cold' soil properties. Although these terms do not directly relate to temperature, management towards 'cold' components can buffer them against the effects of global warming.

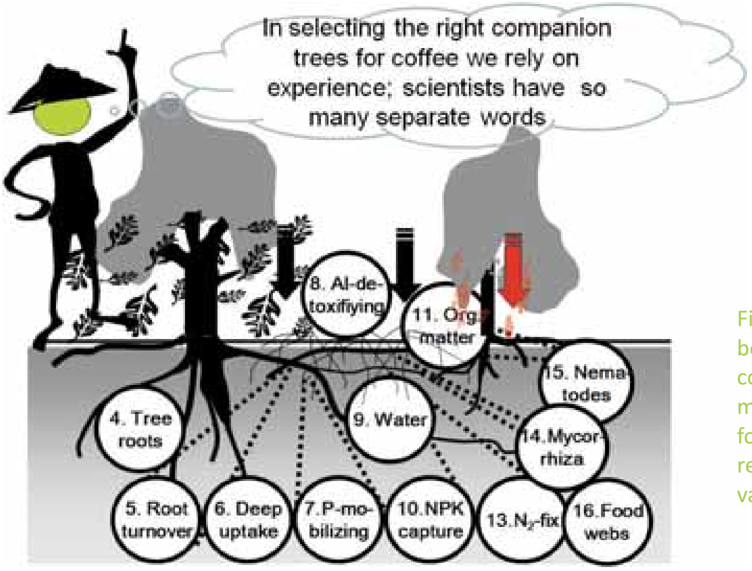


Figure E.4. Interactions between coffee and companion trees involve many separate processes for scientists (numbers refer to chapter titles in van Noordwijk et al. 2004)

## F. Tree growth and dependence on climate

The main point of this chapter is that trees exhibit a range of growth responses and adaptive strategies to differences in environmental factors. A changing climate alters an individual tree's living conditions, recruitment, survival and competitive abilities and through this brings about changes in the composition and dynamics of ecosystems. At the same time, tree species can cope with environmental change by migrating through seed dispersal to new habitats where site conditions are more favourable and can persist at given locations during extreme weather events such as droughts. The resilience of tree species to fast and extreme climate change is, however, not well understood. Identifying the impact of climate variability on tree growth, therefore, has great importance for understanding the reaction of trees to anthropogenic climate change and the contribution of trees to the global carbon cycle.

### Broad patterns: current relations, zones

The geographic distribution of trees is influenced by environmental conditions such as temperature and rainfall (Table F.1). Global warming will have profound effects on the world's biota through influencing these factors. This will cause large-scale redistribution of the growth domains in which particular trees and forest assemblages can thrive. In fact, drastic changes in floral distribution have been a feature of past natural climate change and were experienced during the quaternary ice age. Fossil pollen records and molecular genetic studies, for example, demonstrate that temperate species such as American beech (*Fagus grandifolia*) and red maple (*Acer rubrum*) expanded in distribution from 'refugia' at a rate of around 100 m per year after the Last Glacial Maximum (LGM). In tropical regions, fewer pollen records are available to assess past migrations, but molecular genetic studies suggest, for example, that the important and threatened African medicinal tree, red stinkwood (*Prunus africana*), expanded rapidly in range after the LGM, although certain geographic features (such as the dry Rift Valley in Kenya) acted as barriers to migration in particular regions.

## Tree resilience from physiology to population level

Trees respond to changing environmental conditions at different temporal scales, down to within a few minutes of an alteration. The sum of those activities of a tree, that is, its physiological processes, are expressed in a very complex way in its structure. The basic pattern of cell distribution and cell size is genetically determined, however, it is influenced by external factors to the extent that a large structural variation occurs. Acclimatisation (as an aspect of phenotypic plasticity) is evident in the variation of cell wall thickness, cell size, length and shoots, needles and ring width, but also in the overall shape and architecture a tree attains. Impacts on growth expressed through ring-width series can allow the reconstruction of inter-annual and even multi-decadal climatic variation.

## Trees as keepers of climate history records

Future climate variability will determine the success or failure of trees already established or planted now. We can learn from the ways trees responded to past variability through the study of ‘growth rings’ in trees or ‘dendrochronology’. Time-keeping by trees (that is, dendrochronology) with modern techniques of analysis (Cook and Kairiukstis 1990) has wide application in environmental research (dendroecology), hydrology, glaciology, tectonics/volcanism, geomorphology, in forestry sciences and in climate-change research.

Trees grow radially by adding new layers of wood cells on the inner side of the ‘cambium’. The size, type and cell-wall thickness of wood cells can be modified by external factors. The factors that exert direct or indirect influence on the width and appearance of the annual rings include radiation, temperature, availability of mineral nutrients, water supply and duration of photoperiod (Larcher 2003). A cross section of *Acacia tortilis* wood (Figure F.2) shows variation in vessel sizes and wood density, reflecting seasonal and inter-annual changes in growth conditions marked by tangential parenchyma bands.

In order to interpret growth rings as a reflection of climate variability, sites need to be selected where other sources of variation on tree growth are small or well understood. For time series analysis, replicate tree samples (about 15 per site) are needed, with visual and statistical approaches to guarantee correct cross-dating. Visual techniques utilise pointer years (extremely wide or narrow rings), which can be used to recognise missing or additional (‘false’) rings. Longer time series can be made using archaeological and fossil wood. Similarity of individual curves can be tested statistically with computer programs such as Tree-Ring Chronology Quality Control Analysis (COFECHA) or Time Series Analysis and Presentation (TSAP). Corrections for growth patterns along the typical lifecycle of a tree are needed to interpret correlation with climate data. Isotope analysis of wood ($C^{12}/C^{13}$ ratio) can be used to recognise water stress at the time of wood formation.

Trees forming annual growth rings are found in many regions of the world. With the strong climate seasonality in temperate climates, growth-ring patterns are used as a climate proxy to reconstruct climate for the past 10 000 years. It has been widely assumed that tropical trees do not form annual rings, but many authors have succeeded in using tree rings in tropical trees to determine tree age, understand growth dynamics and to carry out ecological and climate studies (Worbes 1999). In climates with at least two arid months, growth boundaries are usually visible, although distinct bi-modal dry seasons can cause two rings per year. For example, Gebrekirstos et al. (2008, 2011) found for the savannah woodlands of Ethiopia that there was a strong link between tree-ring width and precipitation records (Figure F.1). Furthermore, the co-occurring species (*Acacia* *senegal*, *A. seyal*, *A. tortilis* and *Balanites aegyptiaca*) showed similar responses to external climate forcing, which confirms the formation of one tree-ring per year. Narrow rings correlated remarkably well with past El Niño events and drought/famine periods. Spectral analysis of the mean tree-ring chronology indicated occurrences of periodic drought events, which fell within the spectral peak of the ENSO cycle of 2–8 years. Once calibrated, trees can be used to understand past climate variability in locations where other climate data are scarce (Figure F.1).

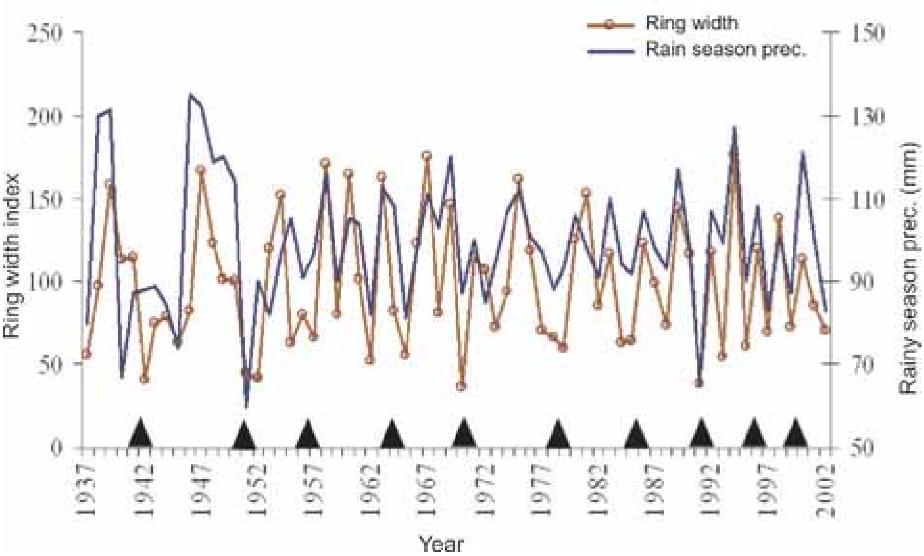


Figure F.1. Mean chronology of four co-occurring tree species from semi-arid woodlands in Ethiopia and rainy season precipitation (June to September). Arrows indicate pointer years (narrow rings), which are correlated with El Niño events and drought/famine periods in Ethiopia. Source: Gebrekirstos et al. 2008

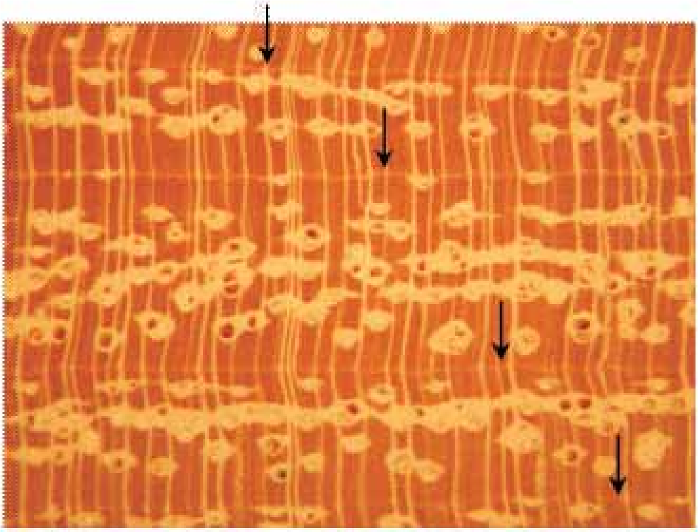


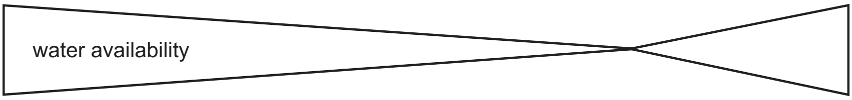
Figure F.2. Cross-section of *Acacia tortilis*. Arrows indicate annual growth boundaries characterised by tangential parenchyma bands

## Challenges of climate variability for trees

Climate change also influences the phenology of tree species, including the timing of leaf emergence, flower initiation and growth, and this varies between different trees. Trees often demonstrate a range of features that can be expected to facilitate adaptive responses to a variety of challenges including climate change, large populations, out crossing, high seed production and high genetic variation in morphology and physiology. All these factors favour the establishment of genotypes containing novel allelic combinations that may be better suited to new conditions.

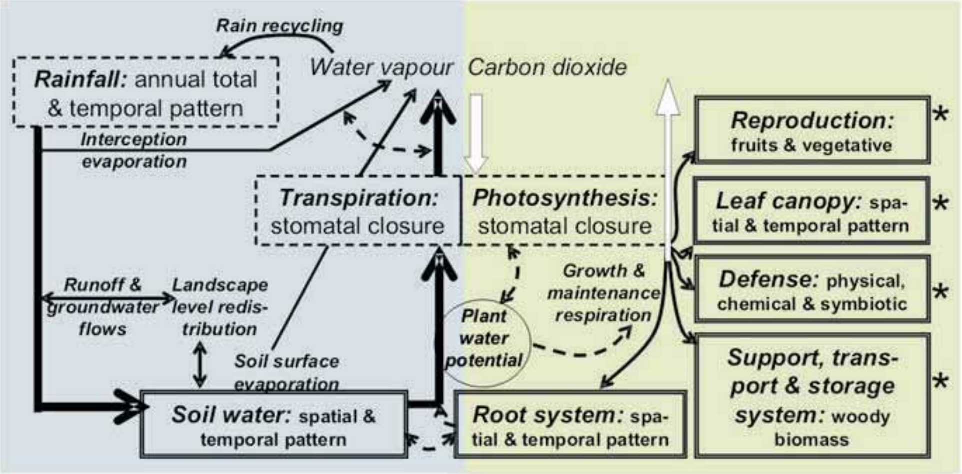
For example, mangroves have high reproductive output and high rates of seedling establishment, which might lead to the assumption that fecundity can compensate for intense harvesting. Coppicing, the ability to produce new shoots from the cut stump or 'stool', is a key element of resilience to disturbance in savannah and Miombo woodlands where successful regeneration by seed is highly susceptible to rainfall seasonality and frequent fire. Trees that produce deep roots can access soil moisture at greater depths than other plants, allowing them to extend their growing period and persist through drought conditions when other plants die. The time taken for dieback of adult trees owing to drought should, however, not be over-estimated and should be considered in periods of months or at most a few years rather than decades. In an experiment in Amazonian forest in which rain through-fall was restricted, Nepstad et al. (2007) demonstrated a lag of three years before the onset of increased mature tree mortality owing to water limitation.

Table F.1: The most important limiting climatic factors for tree growth in major climate zones



| | Subpolar and boreal zones | Humid temperate zone | Arid/subtropical zone | Humid/tropical zone |
|---|---|---|---|---|
| Upper treeline | Coniferous forest | Coniferous forest | Coniferous forest or deciduous broadleaved forest | Evergreen forest |
| | Warm/dry conditions are favourable | Warm/dry conditions are favourable | Warm winters/ moist summer conditions are favourable | Warm/dry conditions are favourable |
| Central region | Coniferous forest/ deciduous broadleaved forest | Deciduous broadleaved forest | Evergreen or deciduous | Evergreen broadleaved forest |
| | Warm/dry conditions are favourable | Warm/humid conditions are favourable | Cool /humid conditions are favourable | Cool/humid conditions are favourable |
| Lower tree limit | Not existing | Not existing | Savannas<br>Limitation by drought | If existing (savannas), cool/humid conditions are favourable |

An essential trait of plants adapted to low-resource environments is that they grow slowly even when an optimal supply of resources is provided. A study on water relations of co-occurring savannah trees coupled with long-term climate growth analysis by Gebrekirstos et al. (2006, 2008) revealed that *Acacia senegal* and *Acacia seyal* showed a marked growth reduction during drought years and recovered to a favourable growth during wet years, which is consistent to their drought sensitivity and opportunistic water-use strategy. In contrast, the drought-tolerant and conservative water users *Acacia tortilis* and *Balanites aegyptiaca* seemed to exhibit relatively small growth reduction and increase in response to drought and wet years, respectively. In addition, slow-growing trees invest more in defence against herbivores and pathogens and allocate a higher proportion of their assimilate in a large root system and higher wood density, thus increasing their survival chances in uncertain environments.



***Legend:*** Solid arrows: material flows (water in left part, carbon in the right); broken line arrows: influences; solid boxes: main fluxes of interest

* indicates potential interest as harvestable product

Figure F.3. Relationship between water and carbon fluxes and pools in tree growth in relation to climate (rainfall pattern, evaporative demand), soil (water flow pathways, storage)

As noted above, tree species can migrate as a response to climate change, by seed dispersal. The speed at which migration is possible depends on the reproductive biology of the species in question and can vary greatly. In general, however, the rate of movement required to combat anthropogenic climate change is greater than the natural dispersal rate in both temperate and tropical regions. At the same time, opportunities for natural migration have been reduced through human activities such as logging and agriculture that result in disjunctions in natural distributions.

Conditions for plant establishment, growth and yield in arid and semi-arid areas are harsh owing to natural and anthropogenic stresses. Of these stresses, drought and soil salinity are the main limiting factors. The area of arid lands worldwide, of around 45 million km$^2$, could be better used for production if these constraints could be overcome. Site–species matching and the deployment of improved germplasm (for example, drought and salinity tolerant) could play significant roles in increasing productivity in such areas. Changes in pollinator abundance and behaviour caused by climate change may result in reduced tree seeding in agroforestry systems and inbreeding in the seed that is produced. For trees that are specifically grown by smallholders for their fruit and nut products, reduced pollination may have significant direct impacts on production. In such cases, losses in productivity could be very large and active management interventions such as introductions of animal vectors (for example, through promoting bee-keeping) may be required.

Climate change effects on tree pest and disease prevalence will often be of most concern. A strong link between infestation and stress of some sort, often related to drought, has been observed in Africa. Warmer and drier climates may exacerbate stress in trees resulting in more areas being predisposed to insect pest attack. Devastating attacks on lodgepole pine (*Pinus contorta*) forests in Canada by the mountain pine beetle (*Dendroctonus ponderosae*) are attributed to milder winters owing to global warming. In this instance, higher winter temperatures have resulted in lower mortality in over-wintering stages of the insect and significant economic losses in timber production have resulted. Conventional breeding approaches to address these new threats are likely to be unsuccessful because the time scales involved in breeding are too long.

## Challenges and opportunities of climate variability for people dealing with trees

In the case of planted trees, human translocation of well-adapted germplasm across sites to match future climate is an option, presuming that climate-change models can, with some certainty, predict how the environment will alter at given locations at given time scales, in order to allow for proper matching. To date, actual examples where 'climate-change matching' has been put into practice for agroforestry species are limited, but one good case is provided by *Prosopis africana* in the semi-arid West African Sahel. Based on an analysis of growth, survival and wood density in field trials in relation to regional rainfall patterns, it was recommended that germplasm transfers of this species should be undertaken in one direction only: from drier to wetter zones/countries (Weber et al. 2008). This advice is in response to drying in the region over the last few decades. A similar distribution strategy for other tree species in Burkina Faso, Guinea, Mali, Niger and Senegal was adopted in a recent International Fund for Agricultural Development project to rebuild and diversify parkland agroforestry systems.

Current centralised models for delivering tree germplasm to smallholders have failed to meet the demand of farmers for tree seed and seedlings. To combat this constraint, in recent decades a participatory approach to tree domestication has been promoted, in which farmers are encouraged to collect and bring into cultivation the genetic resources of indigenous tree species that they find in the landscapes immediately around them. But in the context of rapid environmental change that results in significant geographic shifts in planting domains, it is evident that local sourcing will no longer be an adequate response for germplasm sourcing, because the scale of change will be too great. So there needs to be a revitalisation of national tree seed programs to facilitate the long-distance germplasm transfers that are needed to cope with climate change and a renewed engagement of these programs with local communities so that they can access newly-introduced material.

More wide-ranging international trials are needed to evaluate the characteristics of a broader set of tree species for factors that relate to climate-change responses (such as water-use efficiency, salt tolerance and resistance to key pests and diseases). However, between-country transfer of tree seed for research is becoming more difficult and costly as nations seek to protect their own resources under the Convention on Biological Diversity. There appears to be a lack of collective action, with no one benefitting other than the regulators and managers of the bureaucracy of permits. Future success in addressing climate-change challenges will require recognition by the global community that more effective systems for facilitating germplasm exchange for research purposes are required.

## Intermezzo 11.

### Tree–climate matching: use of existing databases

Like any other plant, tree species occur in biogeographically distinct areas that are based on the history of dispersal opportunities. Anthropogenic dispersal may have turned them into 'invasive exotics' in new areas. Within their biogeographical range, trees and other plants only grow in places where they can at least tolerate the abiotic conditions (such as temperature and water availability that depend in turn on climate and soil) and survive the biotic interactions with other species such as seed dispersers, pollinators, microsymbionts, competitors and diseases (Guisan and Thuiller 2005, Soberón and Peterson 2005). Climate change directly affects only part of this complex of factors.

The WorldClim site (http://www.worldclim.org) provides current and IPCC scenario data at a 1 km resolution. A crude first approach could be to combine the climatic range information, for example, of the Agroforestree tree database, with future climate for any place of interest. This approach, however, ignores the biotic interactions and the associated 'management cost' of growing a desired tree in a given place. For natural vegetation this will not be sufficient. A number of modelling approaches, including the 'maximum entropy' approach of the MAXENT model (Phillips et al. 2006) or boosted regression trees (Friedman et al. 2000) have outperformed more established methods of species suitability mapping (Elith et al. 2006). Where less than 30 occurrence records exist, no model can do well (Wisz et al. 2008).

In the 'Vegetation and climate change in Eastern Africa' project, a high resolution digital map will be prepared for seven countries in Eastern and Southern Africa (Kenya, Ethiopia, Uganda, Rwanda, Tanzania, Malawi and Zambia). The purpose is 1) to identify the main zones of transitions that influence agricultural potential; 2) to predict potential (current and future) distributions of indigenous species in the agricultural landscapes and predict possible genetic variation across distributional ranges; 3) to assist choice of indigenous and exotic tree species for specified purposes in specific locations.

## Intermezzo 12.

### LAAMAs in rural Africa?

Figure C.5 introduced the concept of Locally Appropriate Adaptation and Mitigation Action or LAAMA. What sort of beasts are these LAAMAs? What can they look like in practice? How much diversity can we expect among them? The rationale for adaptation planning is the concern that climate change will further exacerbate current climatic risks from natural climate variability. The rural population in Africa is expected to be among the most exposed, as about 80% depend predominately on small-scale agriculture. Rainfed agriculture is one of the most vulnerable sectors to climate change. A good understanding of the agricultural systems embedded in a landscape is crucial to identifying climate-change impacts that farmers need to adapt to strategically. Two projects in which the World Agroforestry Centre cooperates with partners in Germany and with national and local institutions in Tanzania and Burkina Faso serve as examples of reconciling the uniqueness of each landscape system with a generalised approach for viable climate-change adaptation.

Two scales of trans-disciplinary approaches are suggested to analyse, model and finally integrate all relevant components of agro-landscapes. Land-use functions, aggregating indicators from the three pillars of sustainability, allow for reducing complexity to a reasonable measure.

1) The project striving for Resilient Agro-landscapes to Climate Change in Tanzania operates at a sub-national watershed level, with a focus on socio-economic preconditions and constraints in a region that has already experienced frequent failures of at least one of the rainy seasons. 2) In Burkina Faso, the Adaptation of Land-Use to Climate Change in sub-Saharan Africa project covers a gradient of increasing aridity on a nation-wide grid of observation and trial sites.

Both projects aim to support adaptation planning based on modelled scenarios of possible futures. They test a nested multifunctional landscape approach to cater for the complexity of agro-landscapes and their inhabitants. Both projects have similar aims.

- Use modeling to improve the understanding of climate variability in the study region and their impacts on current land-use systems and respective environmental, social and economic pressures.
- Assess smallholder constraints and opportunities with regard to scenario-based potential climate-change impacts on agriculture and land-use functions.
- Identify a range of suitable good practices in terms of adapted land-use systems for improving the overall adaptive capacity of rural households.
- Make model outputs from different disciplines meaningful for local decision-makers by mirroring them with farmers' perceptions and needs.

The projects identified five essential components for reasonable adaptation planning in the African smallholder context. As these components are interdependent (Figure G.6), the projects aim at feeding the (modelled) projections from one component as input to a directly related other component. This mutual feedback mechanism is expected to improve the validity of these projections and the applicability of their recommendations:

- Records of past and current climate are compiled to understand current constraint and common climate variability. Alternative data sources—such as dendrochronological assessments or drought-relief records—can enhance these data. Historic climate data is also required to calibrate models that allow down-scaling of global circulation models to a fine spatial and temporal scale.
- Remote sensing of vegetation structure and patterns of land-use change and geographic information systems' approaches allow for subsequent upscaling of local model outputs. Vegetation models provide spatially explicit recommendations, for example, for the choice of tree species suitable for future climate scenarios.
- Hydrological models need to be validated on a sub-catchment level and subsequently expanded to water basin scale. These models, in turn, depend on land-use change data and scenarios as well as adequate soil data to provide reliable projections of the larger-scale water budget under each climate-change scenario.
- Soil-crop-tree interactions and plants' competition for space, light, water and nutrients is simulated using adequate and locally validated models (for example, Soil-Vegetation-Atmosphere Transfer (SVAT), Decision Support System for Agrotechnology Transfer (DSSAT), Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS). These models deliver the future distribution of vegetation types and optimised cropping systems based on their habitat requirements and climate scenarios.
- Farmers' participation essentially provides an understanding of locally applied adaptation measures and the socio-economic constraints of smallholder farmers in the study regions. Stakeholder meetings, workshops and interviews are an important tool for feedback and for validating the acceptance and adoption of proposed adaptation strategies among stakeholders.

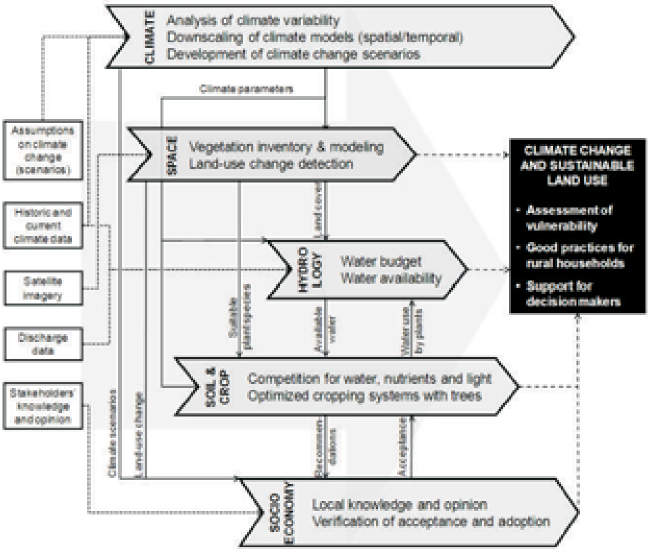


Figure G.6. Modular scheme of an interdisciplinary approach to assess climate-change impacts and develop adaptation options for stakeholders