Federal Ministry of Education and Research

NACHHALTIGES LANDMANAGEMENT

FONA Forschung für Nachhaltige Entwicklung BMBF

Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG

Institute for World Forestry

Participatory research to support sustainable land management on the Mahafaly Plateau in south-western Madagascar

SuLaMa

Planting trees to provide local wood resources and restore degraded dry tropical forests – Principles, challenges and research needs

Planting trees to provide local wood resources and restore degraded dry tropical forests — Principles, challenges and research needs

Laura Prill

February 2016

SuLaMa — Participatory research to support sustainable land management on the Mahafaly Plateau in south-western Madagascar
University of Hamburg

Published by: University of Hamburg
Institute for World Forestry
Leuschnerstr. 91
21031 Hamburg
Germany

Cover picture: Jens Härtel

Contents

1 Introduction

Dry tropical forests harbor several unique and endemic species and provide important goods and services for the local population. Due to the ongoing deforestation and forest degradation, many of these vulnerable ecosystems have been highly disturbed, therefore posing severe threats on the livelihood of rural communities depending on their goods and services. In consideration of an increasing demand for wood resources and a decline in dry forest area, artificial community-based tree planting on degraded arid sites is considered a promising approach to meet local needs and to restore forest conditions close to the original.

Drylands, including dry tropical forests, are defined by the UN as land areas with an Aridity Index of less than 0.65 (United Nations 2011). The Aridity Index is the long-term mean of the ratio of an area's mean annual precipitation to its mean annual potential evaporation (Millennium Ecosystem Assessment 2005). The unique tropical dry forests of the subarid zone in south-western Madagascar exhibit a high number of relictual taxa and an high endemism (Elmqvist et al. 2010; Olson and Dinerstein 2002). Over the last decades south-western Madagascar has experienced a large decline in forest cover that has been primarily associated with slash-and-burn agriculture and an over-exploitation of wood mainly for energy purposes (Brinkmann et al. 2014; Elmqvist et al. 2010). As other tropical dry forests, many of the remaining forest area now suffers from severe forest degradation. The natural regeneration in such degraded sites is commonly prevented by high exploitation rates, grazing pressure, long periods of drought leading to high rates of seedling desiccation, mortality and a slow growth, and frequent fire occurrence. Disturbed sites are likely to be colonized by invasive species or those common for degraded sites that suppress the establishment of native forest species. Such processes often result in the extinction of valuable (endemic) species, a general decline in biodiversity and a shortage in local forest resources. In consideration of the increasing population growth in Madagascar and the population's high dependence on natural resources, e. g. food, energy, medicine (Brinkmann et al. 2014), this poses high uncertainties on the livelihood of rural households and might enhance already prevailing poverty. Human interferences such as the artificial planting (reforestation) of native species in a community-based approach can counteract these developments and provide additional wood resources, thereby mitigating poverty and helping in the ecological restoration and/or rehabilitation of degraded sites. In this regard, reforestation can be a promising approach to provide alternatives to deforestation while supplying local needs (e. g. natural resources and income).

In the past, however, several attempts to reforest degraded sites have failed or been of limited success due to poor knowledge of predominating ecological conditions (e. g. inappropriate site selection and matching), a poor understanding of native species biological and ecological demands and their reproduction patterns, unsustainable management techniques, poor institutional arrangements (e. g. unclear tenure rights) or the incapability of reforested sites to provide a wide range of goods and services (CIFOR Rehab Team 2004; Gilmour et al. 2000; Lamb and Gilmour 2003). The success of reforestation activities is, therefore, highly dependent on the understanding of a complex mixture of socio-economic and political prerequisites on the one hand and a sound knowledge of site-specific ecosystem functioning, species ecology and phenology on the other hand. These aspects together build a reliable fundament on which reforestation management decisions can be based on. Without these prerequisites and know-how any approach to reconcile human demands with an ecosystems ability to provide goods and services is at risk in the long run.

In the following, we discuss challenges, prerequisites and ecological and technical aspects for the subarid zone of Madagascar that need to be considered prior to any artificial planting activity and present (community-based) management options that have been associated with successful plantings in other parts of the tropical dry tropics. Although the individual reforestation success depends on site-specific ecological and socio-economic conditions, it can be assumed that many of the following aspects hold true for the subarid zone of south-western Madagascar. We generally assume that artificial planting activities in this region — as in other tropical dry forests — will be performed for two reasons: The restoration or rehabilitation of degraded sites and forests and the production of wood resources in a relatively short period of time. Both attempts can be realized separately or jointly on one site. Plantings realized primarily for the production of timber or charcoal might for example serve as beneficial tools for rehabilitating degraded lands. Enrichment plantings, the framework species method, interplanting of supportive trees, e. g. leguminous plants, or the establishment of (native) mixed-species plantation stands for the production of wood resources are examples for reforestation attempts that address both objectives to a varying extend. “Reforestation”, in this context can, therefore, refer to many forms ranging from the establishment of tree plantations of exotic species to the attempt to recreate the original forest type and structure by using native species (Le et al. 2012). The purpose of “restoration” efforts is to re-establish the assumed “structure, productivity and species diversity of the forest originally present at a site”, while “rehabilitation” refers to re-establishing the productivity and some, but not necessarily all, of the species originally present. Restoration of original forest structures can be achieved by both direct planting of (endangered and valuable) species, by catalyzing the natural regeneration of these through the planting of supportive (native) species or by the reforestation of abandoned land with the aim to produce timber or charcoal and thereby reduce the pressure on primary forests (passive restoration) — provided that they are protected from further disturbances (Lamb and Gilmour 2003).

Although, some aspects might apply more to the production of wood than to a restoration/rehabilitation effort (and vice versa) we do not focus on or suggest one single approach since there cannot be a one-size-fits-all solution. We rather give an overview of potentially advantageous management tools suitable for the intended above-mentioned objectives and related research needs while only briefly dealing with socio-economic, institutional and financial issues. With the present report we hope to provide valuable input for programs associated with the planting in these regions.

2 Institutional, political and social prerequisites

There are multiple preconditions for the successful implementation of long-term planting attempts in rural areas. In the following, some of these aspects are presented shortly — a detailed description is beyond the scope of this report. Detailed information on the general institutionalization and implementation of community-based forest management is given by FAO (2012).

Some afforestation projects in the past have not been successful in the long-term because of poorly implemented institutional structures, a lack of adequate forest policies and unsustainable management strategies. Major political and institutional conditions necessary for implementing reforestation activities in rural communities concern for example the:

- Legal framework of reforestation projects: forest regulations, transfer of tenure rights
- Financial and practical support by e.g. organizations or institutions (such as development cooperations, NGOs)
- Creation of incentives for villagers and communities to participate in a reforestation approach (e.g. income and tenure rights)
- Participatory development of adequate management techniques in a community-based approach with project partners and local communities
- Training of local population in planting and managing (enriched) dry forests sustainably

A crucial aspect is the creation of incentives for the population to participate in the planting of trees. Common incentives are the generation of incomes (through e.g. the sale of charcoal produced from the reforested sites) and the granting of long-term use rights to local farmers that need to be guaranteed through legal frameworks. In areas with a high reliance on animal husbandry, the protection of seedlings and young trees against grazing for at least 5–10 years is a crucial step towards the successful implementation of reforestation activities, see also subchapter 3.8. This, however, might affect traditional community practices. All preconditions have to be secured in the long-term and are therefore likely to reach beyond the duration of research projects.

A successfully implemented reforestation approach for example has been realized since 1996 in the North of Madagascar where 9000 ha of degraded savannah were afforested in a community-based approach in the Diana Region. The primary aim of this project is to supply the region with sustainably produced charcoal and reduce the pressure on natural forests and its biodiversity. In the community-based approach small farmers and villagers are motivated to participate in the management of energy wood plantations established on community owned land (village-based individual reforestation, "Le reboisement villageois individual"). Farmers and communities, which participate voluntarily, are trained in planting and managing these plantation forests in a sustainable way. One main component of the approach is the attribution of individual land titles to participants and the granting of long-term use rights (Etter et al. 2014; Lopez 2013). Forest management responsibilities are thereby transferred to local villagers. For more information on the community-based project, see GTZ/GREEN-Mad (2007) and Miranda et al. (2010).

3 Management principles for reforestation attempts

The success of reforestation activities relies directly on the management strategies (e.g. selection of species and silvicultural treatments) that are applied to a specific site, species and forest stand. Major aspects to be considered during the planning process are the

- Information gathering on the current situation (e.g. local uses of forest resources, local site conditions, native species composition and ecology)
- Reforestation objectives
- Identification of available sites
- Reforestation design (layout)
- Selection of species (selection of trees with desired characteristics, of best provenance and seeds, site matching)
- Seeding, planting and seedling growth (direct or indirect seeding, planting density and seed production)
- Silvicultural treatments (e.g. thinning and weeding)
- Control of fire and grazing
- Harvesting operations (e.g. techniques)

For the dry forests of south-western Madagascar — as for most of the tropical dry forest regions — knowledge about local ecosystems, their species composition and ecology is poor. This, together with the harsh environmental and climatic conditions, places several challenges on the implementation of reforestation projects. Comprehensive investigations are therefore crucial for the success of reforestation activities. In the following each of the above presented aspects is further elaborated. The temporal sequence of the management and planning steps potentially needs to be modified and adapted to the initial situation. Associated uncertainties, challenges and potential research needs of several aspects are given in boxes below the single aspects.

3.1 Gathering of background information

Prior to any reforestation activity, the gathering of information on social structures, forest policies, environmental conditions, local needs, traditions etc. is essential. This involves the use of all existing experiences and data and includes information on the use of forest resources, practiced land use management techniques and environmental data such as the local climate, soil texture and type, nutrient and water availability and present (and initial) species composition in a region. Information on the local communities are best collected by conducting comprehensive community surveys. The involvement of the local population in the planning and management process as well as the incorporation of the local needs into the reforestation attempt is required for the success of any planting approach.

3.2 Defining the objectives

Clear definitions and ranking of all objectives is crucial at the beginning of any tree planting project. In the south-west of Madagascar, there are two major reasons for the need of artificial tree plantings. Due to the high reliance on wood as the population's primary energy resource, severe climatic conditions and widely diminished dry forests (Brinkmann et al. 2014), additional forest resources are urgently needed to provide the local communities with fuel- and construction wood as well as non-timber forest products. The high rate of endangered (mostly endemic) plant and animal species leads to the demand for forest restoration or rehabilitation projects aiming at conserving species at risk and restoring original forest conditions to the best possible extend. Combining both objectives by fostering the regeneration of native (endangered) species through planting of trees aimed at producing timber or charcoal can in this regard be promising.

3.3 Selection of available sites and their characterization

At the beginning of the reforestation attempt, available (and suitable) sites for planting activities have to be identified. The kind of sites depend on the objective, budget and intended size of the project, both degraded fallow land or openings in degraded forests are possible. Planting sites are ecologically characterized by their annual precipitation, dry season length, monthly maximum, minimum and annual mean temperatures and their soil properties (e.g. soil texture, nutrient availability and pH). The site characterization is important for the introduction of suitable (potentially non-native, see also subchapter 3.5) species that foster the colonization of native trees and for planting activities performed to produce a high quantity of wood biomass in a short period of time. Successful site matching is determined by the requirements of the species to be planted. As preferably native species are used (see subchapter 3.5), the site matching might be facilitated.

For the restoration of abandoned land, the availability of seed sources is critical and is likely to be enhanced in the vicinity of (remnants of) natural forests. Establishing reforestation sites in the proximity of intact forests might, therefore, foster the natural regeneration of degraded land, see also box 3.5.

Box 3.1: Research needs for site selection

The role of natural forests in the vicinity of reforestation sites should be evaluated.

3.4 Choosing a reforestation design

The design chosen to meet the objectives depends on the predominant ecological conditions on available sites, the weighting of each objective and stakeholder interests (e.g. population needs and traditions). Possible approaches are:

Mosaic structures: Assuming that trees are artificially planted for several objectives (e.g. conservation and restoration purposes and the production of wood resources), a possible attempt is to create mosaic structures where each individual objective is realized on different sites. The production of timber in this approach can be realized via newly established relatively fast growing (native) tree stands whereas the conservation of species is primary conceived on other sites (e.g. through enrichment plantings in openings of degraded forest sites).

Joint approach: all objectives can also be realized on the same area. Those systems can be more diverse but might be economically less feasible and more challenging to implement.

Agroforestry systems that combine the management of crops and trees on one site.

Framework species method: The so called "framework species method" that includes the planting of 20–30 indigenous tree species to re-establish a basic forest structure and facilitate the introduction of native species and thereby increase native biodiversity is an option for the restoration and rehabilitation of dry tropical forests and is discussed by Blakesley et al. (2002). Framework species are fast growing species that rapidly shade out weeds and attract animals for example with fruits. Introducing trees of such species on degraded sites can facilitate the natural restoration process towards the desired species composition (i.e. the original one).

Enrichment planting: Interplanting of desired species on degraded forest sites. Enrichment plantings are also conducted to improve ecological conditions (increase diversity) in (single-species) plantation forests.

Plantations: Tree stands of fast-growing species often established for the commercial production of timber or charcoal in high volume in a short period of time.

3.5 Selection of species

Besides the definition of the objectives, the success of reforestation activities is primarily determined by the species selection. The choice of species is a complex decision influenced by the management objectives (and closely related to the desired wood product, e.g. charcoal vs. construction wood), local site conditions, especially precipitation and soil properties, and the species autecology. Main questions determining the choice of species are (adapted from Onyekwelu et al. 2011):

- What is the purpose of the reforestation activity?
- Which species are potentially available for planting?
- Which species will grow on the available sites and how well will they grow?

For the production of timber or charcoal there are several requirements for species to be planted. To grow successfully and to be economically feasible, selected species need to provide a relatively fast growth and be easy to manage. For construction purposes, species should preferably form straight stems and be durable whereas for charcoal purposes the ability to coppice, i.e. the ability to re-sprout quickly after cutting, is recommended. Species that are primarily planted for the production of (fuel)wood or charcoal should further show a high productivity per unit area. Generally, species should not negatively affect important ecosystem characteristics such as the soil, groundwater table or valuable native species. If reforestation requires the planting of non-indigenous species, following Onyekwelu et al. (2011), the tree species' native habitat range can initially provide the best guide to the required type of planting site (site matching).

In order to reverse the trend of forest degradation and deforestation, e.g. for conservation purposes or the sustainable management of forests, the introduction of certain species can be used to accelerate the successional process towards a desired (original) species composition (Khurana and Singh 2001a). This is of importance as species that naturally colonize degraded sites are often plants typical for disturbed land (sometimes invasive plants) and not those of the original species structure. Such species may, however, persist and dominate the ecosystem for a long period of time (Khurana and Singh 2001a). The restoration or rehabilitation process should counteract this development. The majority of dry forest species are typically wind-dispersed. Interplanting animal-dispersed species can augment the diversity and help restore original species composition. For the reforestation of abandoned land, the selection and planting of framework trees (see subchapter 3.4) can be beneficial (Blakesley et al. 2002). Attracted animals disperse seeds of non-planted species and thereby foster the colonization of other native plants.

Planting understorey and overstorey trees that provide different products (e.g. charcoal or construction wood) or the interplanting of nitrogen-fixing, leguminous trees are generally beneficial tools that can be incorporated in the management process to increase biomass and foster the natural regeneration of native species in a degraded forest or reforested site. Severely degraded fallow sites or degraded forests might generally profit from the "preparation" with large-fruited shade-intolerant tree species that are able to promote the regeneration of native late-successional species under their canopy (Griscom and Ashton 2011).

For any large-scale planting project a high quantity of seeds of good quality needs to be available. However, the lack of reproductive material is seen as one of the most important reasons for the few large-scale plantings with native species (e.g. in plantations, Onyekwelu et al. 2011). Hence, successful seed production is the prerequisite for a species to be chosen for broad plantings, see below.

3.5.1 Native versus exotic species

To facilitate the restoration of degraded dry forests, to fulfill the multiple requirements on species and to favour species diversity at all scales (Higman et al. 2005), a mixture of different species and ages is crucial. The decision of whether to include exotic (non-native) species is influenced by the interplay between the reforestation objectives, the predominating ecological conditions determining suitable native species and their seed availability. There are several advantages associated with non-native species. These are the relatively fast and undemanding growth, well-established manage-

Box 3.2: Research needs for species selection and site matching

One of the biggest challenge in the dry tropics is the selection of species that suit the project objectives. These are mainly species that show good reproduction patterns and have a relatively fast growth. Following the general objective of a planting project, a first pre-selection of trees out of the regional species pool should be made based on the most favored tree characteristics e.g. ability to coppice, fast growth or fruit type for the suitability as framework trees. Small-scale trials should be established for these species and survival rates and growth performances of trees (and seedlings in nurseries) precisely documented. Successfully grown species can then eventually be investigated for best provenances. Selected species are subsequently planted in large-scale trials. Several species combinations are examined for best choice. The identification and establishment of framework tree species should be implemented in the planning process to restore a basic structure and catalyze the regeneration of native plants (Blakesley et al. 2002).

Small and large scale field trials are essential to examine the project-specific species suitability and occurrence of negative ecological impacts.

ment, the broad knowledge about ecological characteristics and habitat ranges, silvicultural experiences and availability of high quality seeds in a high quantity. In spite of this, the introduction of exotic species also has several disadvantages. First, there is a potential risk that planted species may become invasive and suppress desired native species by outcompeting them for water or nutrients. Second, non-native species often produce a limited range of ecosystem goods and services (Lamb et al. 2005) and can therefore have a reduced overall value for the population and ecosystem. This may reduce the acceptance of reforestation activities in communities. Third, afforestation with exotic species generally offer less habitat and food for native animal species than with native species.

Native species on the other hand, are better adapted to the environment and are, therefore, more likely to introduce or facilitate the regeneration of other (native) plant species and to attract animals. They are further better capable of providing several goods and services for the local population (e.g. energy, food, medicine) and the ecosystem which increases the importance and overall value of reforestation activities in a community. Disadvantages associated with native species are often the lack of experience and knowledge regarding their management and the challenge to produce high quality and quantity of seeds.

Because of the mentioned reasons, including native species is strongly advised for projects aiming at rehabilitating degraded sites and providing the population with valuable resources. As the ecological impacts of exotic species are not predictable, when they are planted, careful observation and research of their impacts in multistage trials is necessary.

3.5.2 Selection of provenances

Species populations of different origins (provenances), growing in different environments may show different phenology and growth patterns. The consideration of provenances, i.e. the most productive provenances within a species for a given area, is therefore essential for a successful reforestation effort (Günter 2011; Khurana and Singh 2001a; Onyekwelu et al. 2011). Some variations in seed provenances are recommended for an increased genetic diversity, especially in terms of the resilience to insect attacks, disease outbreaks or unpredictable events that are — for example — associated with climate change. In case of changing conditions, it is more likely that one of the chosen provenances will be resistant and can cope with the current development when the genetic diversity is higher.

3.6 Seeding, planting and seedling growth

As mentioned earlier, seeds of species to be planted need to be available in high quantities. This remains challenging as seeds or seedlings from native species can seldom be purchased on local markets (as can be seeds of exotic plantation species). Therefore, seeds need to be collected from trees that show desired qualities. Depending on the germination demands of individual species, seedlings are either raised in nurseries and then transferred and planted on their permanent site (indirect seeding) or directly seeded on the reforestation sites. Indirect seeding is preferred to reduce seedling mortality when seeds are scarce and do not easily germinate and grow under harsh conditions but is more cost intense. Following Pandey and Prakash (2014), direct seeding is preferable to nursery-grown seedlings in terms of root development because direct seeded plants establish deeper root systems. However, indirect seeding is usually the common applied method.

Soil moisture and rainfall quantity are one of the most important factors influencing seed germination and seedling growth. Many seeds of dry tropical tree species therefore mature during the dry season and are dispersed at the beginning of the rainy season (Khurana and Singh 2001a) when germination conditions are good. Seedling mortality could, hence, often been reduced by increasing soil moisture in nurseries. Collecting seeds at the end of the dry season and seeding them (or planting nursery-grown seedlings) when soil moisture is sufficient — commonly at the beginning of the rainy season — is, therefore, recommended (Blakesley et al. 2002; Vieira and Scariot 2006).

Individual species favor different environmental conditions for germination and seedling growth. An adequate spot for the planting or seeding on permanent sites is, therefore, crucial for the survival and viability of trees under dry conditions. Species differ for example in their shade and light tolerance at various development stages. Considering to plant seedlings in open areas (for light tolerant species) or under the canopy of existing trees (for shade demanding species) will increase the chance of a higher survival rate. This is especially important since water stress is the dominant factor causing seedling mortality during the dry season. Shading might prevent seedling mortality (Fredericksen 2011) but is dependent on the individual demand of a given species.

Application of fertilizer — during the growing season commonly nitrogen or potassium (Onyekwelu et al. 2011) — may enhance the seedling growth but is generally very costly. The inoculation with mycorrhiza is further discussed to increase the access of seedlings to water and nutrients (particularly of phosphor) (Khurana and Singh 2001a). Trenching is reported by Khurana and Singh (2001b) for reducing belowground competition in the permanent sites. Other soil preparations such as mulching, terracing or the ash-bed method can be necessary when seedlings or seeds are planted on their permanent sites.

Regarding the planting of seedlings (or seeds), an adequate planting density is critical in terms of the low soil moisture.

3.6.1 Seed distribution

Individual seed distribution strategies of species are important for the natural regeneration process of (planted) species. The knowledge of these processes increases the chance to respond to species-specific needs. Many of the dry tropical forest species are wind- or gravity-dispersed. Wind-dispersed seeds are generally known to propagate for a few hundred meters from their seed source and are therefore likely to distribute relatively easily. Some animal-dispersed trees on the other hand fail to propagate due to the absence of vertebrates (e.g. lemurs, Pandey and Prakash 2014). Including those trees will augment diversity. On the other hand the introduction of species that attract seed dispersers should also be considered.

Box 3.3: Challenges and research needs of seed production and physiology, seeding and seedling growth

One major challenge associated with the collection of seeds is the request of high quality seed sources, i.e. healthy trees with desired characteristics such as a fast growth, in an adequate quantity. Since many of the desired species do not occur frequently, especially when being endangered, the selection of adequate trees can spread to an area of several hundred hectares (Onyekwelu et al. 2011) and, hence, requires high effort. To overcome this problem, vegetative propagation (from stem cuttings) has been practiced in some places but experiences in dry tropical forests are few (Bellefontaine et al. 2000). The technique should generally, however, only be of interest for increasing the wood production but is debatable in terms of the genetic diversity since vegetatively propagated plants are clones of their donor tree. It is therefore recommended to establish seed nurseries and stands to facilitate later seed production.

The reproduction of plants is generally influenced by various environmental factors such as temperature, light, soil moisture and nutrients and predators (Khurana and Singh 2001a). Species-specific research should focus on the optimal time of seed collection, required seed treatment, seed storage conditions, related maximum duration of seed viability and time to germinate. Also the ability to remain dormant — a strategy to avoid unfavorable environmental conditions for seedling establishment — that is particularly associated with seeds of species from tropical dry forests has to be considered as they often require specific dormancy-breaking treatments (see also Bellefontaine et al. (2000) for more information). Research should moreover address the species-specific duration and requirements for germination (e.g. optimal temperature for seed germination) and seedling growth (e.g.

exposure to light) and species-specific optimal time and site conditions for planting. The identification of germination niches can further maximize the germination of desired native species (Khurana and Singh 2001b). A comprehensive overview about the ecology of tree seed and seedlings and its implications for tropical forest conservation and restoration is given by Khurana and Singh (2001b).

The seed collection, seedling growth in nurseries and the planting of different species can be logistically challenging because fruits of different species mature at different times of the year and vary considerably in their dormancy and germination. Blakesley et al. (2002) give a good example for the implementation of such investigations and their problems.

Information required for direct and indirect seeding are comparable but both systems might not be adequate for all species. Therefore, the preference for one seeding method over the other needs to be investigated. Pandey and Prakash (2014) provide an overview of potentially suitable species for direct seeding. Taking into account variations in germination patterns, seedling growth and durability among provenances, research should also focus on the identification of the best origins.

The establishment of nursery and field trials for the careful investigation of seedling growth in various plot designs (e.g. varying planting densities) and eventually for the production of seeds of desired species, as well as the monitoring of reproduction patterns, is therefore essential.

3.7 Silvicultural treatments to foster the growth of planted species

The decision to apply silvicultural treatments such as weeding or thinning depends on the planted species, the forest stand, the effort and available budget. Since the biggest challenges in dry forests are a low survival rate of seedlings and — for the production of timber or fuelwood — a relatively slow growth, the application of treatments that foster the growth of desired species is recommended. The control of competing vegetation at various plant development stages can increase the plant growth and biomass production. A weed-free zone of one meter diameter around trees from the time of planting until the canopy closures is, for instance, suggested by Onyekwelu et al. (2011) for trees grown in plantations. The use of chemicals should be avoided in a region of high diversity and conservation value since their effects on the ecosystem are not fully predictable and their broad application is commonly too expensive for local villagers. Manual weeding is therefore generally preferred to the application of herbicides. Thinning of undesired and competing trees (e.g. for light) or opening of canopies may be beneficial where the growth of desired species should be favored. However, since forest structures in tropical dry forests differ from those of moist tropical forests, other silvicultural treatments (e.g. to promote straight stems) often applied might not be adequate in dry environments as the feasible stem density might be insufficient. The pre-selection of trees that naturally show desired characteristics, such as a straight stem for commercial use, is preferable. For the production of fuelwood, commonly

Box 3.4: Research needs of silvicultural treatments

Research should examine the potential of silvicultural treatments in enhancing tree growth. Particularly the investigation of weeding, the interplanting of nitrogen-fixing trees and the use of leguminous herbaceous cover to enhance seedling and tree growth is recommended. Hereby, the interaction between planted tree species and herbaceous plant cover has to be taken into account and observed as the herbaceous plant cover can have both a facilitative or competitive role. Treatment-specific records of tree performance are essential in trials.

no thinning treatments are necessary. The application of fertilizer can enhance seedling growth on nutrient-poor soils but might be too costly for local communities. Introducing nitrogen-fixing species can be an alternative — as mentioned earlier. Leaving harvest residues on site and avoiding soil compaction are further tools to maintain or enhance site fertility (see box 3.4).

3.8 Controlling fire and grazing

Although fire events may stimulate the seed germination of some adapted species (Khurana and Singh 2001a), repeated burning commonly negatively affects seedling and tree growth and alters species composition towards a structure typical for disturbed regions and should, therefore, be avoided.

Grazing pressure in many tropical dry forests is known to be a factor reducing the natural regeneration of species severely and affecting species composition. Soil compaction through cattle might further contribute to reduced regeneration in heavily grazed areas. In this regard, planted seedlings

Box 3.5: Research needs of grazing and fire prevention

The potential of reduced grazing pressure to increase the chance of natural regeneration of native forest species should be investigated. (Living-)Fenced test sites established in a spatial gradient to (patches of) natural forests are recommended to investigate both the general impact of grazing on plant regeneration and the role of natural forests in the vicinity of areas to be restored.

The impact of manual weeding is investigated by the comparison of weeded and non-weeded sites that otherwise show comparable conditions.

should be protected from these impacts, which can be very challenging in regions where cattle roaming has a high cultural importance. The enclosure of sites is therefore a promising tool in the restoration of forests. Because plants grown from seeds generally show a slow growth, they further require a (sometimes very long) period of protection (Bellefontaine et al. 2000). Although grazing has also been used to control invasive herbs and fire (reduction of fuel loads) in some places, the negative influence on the regeneration of forest species can be too high to justify these techniques (Stern et al. 2002). Introducing species less susceptible to predation and browsing (Vieira and Scariot 2006) while still meeting the project objectives might be useful where the construction of enclosures is difficult (see box 3.5).

3.9 Harvesting operations

Common harvesting techniques applied in the sustainable management of wet tropical forests should be considered. Species-specific minimum commercial diameter for the tree harvest should be realized (see box 3.6).

Box 3.6: Challenges and research needs of harvesting operations

To ensure a sustainable management and use of wood resources a specific minimum diameter for the harvest has to be identified on the species level. This, however, remains challenging since few experiences and information exist on species growth for the region. First harvest plans should be developed with the help of the local population that are usually familiar with the growth of local trees. Regular growth records and inventories are recommended to investigate the individual growth patterns of tree species and planted or enriched stands.

4 Implementation of reforestation attempts

In the previous chapters, we have described possible options and aspects for the reforestation of degraded (forest) sites. The various planting-related research needs that determine the success of reforestation attempts outlined can, however, only be realized when funding and organizational issues are addressed during the reforestation planning. Due to the lack of financial support, large-scale investigations (e.g. prolonged trials for species-site matching) are often not feasible (Schneider et al. 2014). First small-scale seedling production and tree nursery trials in school or university-based programs may be an option for realizing such investigations, as they only have low associated costs, few logistical challenges and low area requirements. Those cost-efficient small-scale trials can provide very valuable information for subsequent reforestation projects. It is therefore highly recommended to promote the establishment of these trials as any reforestation attempt is based on long-term observations. The cooperation with local seed institutions such as the "Silo National des Graines Forestières" (SNGF) can considerably reduce efforts related to the first collection of seeds. In general, all existing information and experiences from former projects should be used to minimize the research needs.

5 Conclusion

In the previous chapters we have focused on ecological and technical aspects associated with successful reforestation attempts. The mentioned socio-economical and institutionally aspects are equally important and need to be addressed for a successful reforestation approach.

The aspects presented in this document have shown that there are high uncertainties and challenges associated with artificial tree plantings in the subarid zone of south-western Madagascar. These are in particularly associated with the selection of suitable species and widely unknown individual reproduction patterns of native species.

Nevertheless, it could also be shown that several management techniques, associated to the different development stages of planted species, exist. This results in a high potential for an improved tree growth, seedling survival rate and can foster the natural regeneration of native trees, thereby restoring original conditions and preventing the loss of biodiversity. The suitability of presented management options needs to be validated through careful observations and the establishment of long-term multistage field trials. In particular, the knowledge of species biology and reproduction patterns need to be improved to optimize the artificial seeding, planting, seedling and tree growth in both nurseries and permanent reforestation sites, thereby ensuring an increased survival rate and an improved tree performance. The introduction of natural management tools such as the establishment of framework trees or the mixture with leguminous trees or herbaceous cover should be investigated as a possibility to increase the growth under such harsh conditions. A better understanding of species environmental requirements (shade demanding or light tolerant) will further increase the chance of a successful artificial planting approach.

The careful observation of (negative) effects on the ecosystem induced by the planting activities is highly recommended at every stage of the process. Without the establishment of long-term trials in a multistage approach (from small to large scale trials) the success of artificial tree planting activities remains at high risk.

Bibliography

Bellefontaine, R., A. Gaston, and Y. Petrucci (2000). **Management of natural forests of dry tropical zones**. Vol. 32. FAO conservation guide. Rome and [Great Britain]: Food and Agriculture Organization of the United Nations.

Blakesley, David, Stephen Elliott, Cherdsak Kuarak, Puttipong Navakitbumrung, Sudarat Zangkum, and Vilaiwan Anusarnsunthorn (2002). "Propagating framework tree species to restore seasonally dry tropical forest: Implications of seasonal seed dispersal and dormancy". **Forest Ecology and Management** 164.1-3, pp. 31–38.

Brinkmann, Katja, Fanambinantsoa Noromiarilanto, Rakotomalala Yedidya Ratovonamana, and Andreas Buerkert (2014). "Deforestation processes in south-western Madagascar over the past 40 years: What can we learn from settlement characteristics?" **Agriculture, Ecosystems & Environment** 195, pp. 231–243.

CIFOR Rehab Team (2004). **Review of Forest Rehabilitation initiatives: Lessons from the Past**.

Elmqvist, T., M. Pyykönen, and M. Tengö (2010). "Spontaneous Regeneration of Tropical Dry Forest in Madagascar: The Social–Ecological Dimension". **Reforesting landscapes**. Ed. by H. Nagendra and J. Southworth. Vol. v. 10. Landscape series. Dordrecht, London, and New York: Springer, pp. 297–313.

Etter, H., S. Sepp, K. Ackermann, and Plugge, D. and Schauer, M. (2014). "Modernization of wood energy in northern Madagascar". **ETFRN News 56: November 2014**.

FAO (2012). **Guidelines for institutionalizing and implementing community-based forest management in Sub-Saharan Africa**. Accra: Food and Agriculture Organization of the United Nations.

Fredericksen, T. S. (2011). "Review Silviculture in Seasonally Dry Tropical Forests". **Silviculture in the Tropics**. Ed. by Sven Günter, Michael Weber, Bernd Stimm, and Reinhard Mosandl. Vol. 8. Tropical forestry. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 239–260.

Gilmour, D. A., VÄƒn Sá»£n Nguyá»½Ì‚n, and Xiong Tsechalicha (2000). **Rehabilitation of degraded forest ecosystems in Cambodia, Lao PDR, Thailand and Vietnam**. Conservation issues in Asia. IUCN Asia.

Griscom, H. P. and M. S. Ashton (2011). "Restoration of dry tropical forests in Central America: A review of pattern and process". **Forest Ecology and Management** 261.10, pp. 1564–1579.

GTZ/GREEN-Mad (2007). **Le reboisement villageois individuel: Stratégies, techniques et impacts de GREEN-Mad (MEM-GTZ) dans la région d'Antsiranana Madagascar**. Ed. by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. Eschborn.

Günter, Sven (2011). **Silviculture in the tropics**. Tropical forestry. Berlin, Heidelberg, and New York: Springer.

Higman, S., J. Mayers, S. Bass, N. Judd, and R. Nussbaum (2005). **The sustainable forestry handbook: A practical guide for tropical forest managers on implementing new standards**. 2nd ed. Earthscan forestry library. London and Sterling, VA: Earthscan.

Khurana, Ekta and J. S. Singh (2001a). "Ecology of seed and seedling growth for conservation and restoration of tropical dry forest: A review". **Environmental Conservation** 28.01.

Khurana, Ekta and J. S. Singh (2001b). "Ecology of tree seed and seedling growth: Implications for tropical firest conservarion and restoration". **Current Science** 80.6.

Lamb, D. and D. A. Gilmour (2003). **Rehabilitation and Restoration of degraded Forests**.

Lamb, D., A. L. Hoe, V. Poopathy, A. S., and P. B. Durst (2005). **Helping forests take cover: On forest protection, increasing forest cover, and future approaches to reforesting degraded tropical landscapes in Asia and the Pacific**. Vol. 2005/13. RAP publication. Bangkok, Thailand: Food and Agriculture Organization of the United Nations, Regional Centre for Asia and the Pacific.

Le, Hai Dinh, Carl Smith, John Herbohn, and Stephen Harrison (2012). "More than just trees: Assessing reforestation success in tropical developing countries". **Journal of Rural Studies** 28.1, pp. 5–19.

Lopez, P. (2013). **Sustainable wood energy value chains: experiences from Madagascar: Example from the German Malagasy Environmental Programme**. Berlin.

Millennium Ecosystem Assessment (2005). **Ecosystems and human well-being. Desertification synthesis: World Resources Institute, Washington, DC.** Washington, DC.

Miranda, R. C. de, S. Sepp, E. Ceccon, S. Mann, and B. Singh (2010). **Sustainable Production of commercial Woodfuels: Lessons and Guidance from two strategies**. Ed. by The International Bank for Reconstruction and Development/THE WORLD BANK GROUP. Washington, DC.

Olson, D. M. and E. Dinerstein (2002). "The Global 200: Priority ecoregions for global conservation". **Annals of the Missouri Botanical Garden** 89(2), pp. 199–224.

Onyekwelu, J. C., B. Stimm, and J. Evans (2011). "Review Plantation Forestry". **Silviculture in the Tropics**. Ed. by Sven Günter, Michael Weber, Bernd Stimm, and Reinhard Mosandl. Vol. 8. Tropical forestry. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 399–454.

Pandey, D. N. and N. P. Prakash (2014). "Tropical Dry Forest Restoration: Science and Practice of Direct Seeding in a Nutshell". **RSPCB Occasional Paper** 7.

Schneider, Tina, Mark S. Ashton, Florencia Montagnini, and Paciencia P. Milan (2014). "Growth performance of sixty tree species in smallholder reforestation trials on Leyte, Philippines". **New Forests** 45.1, pp. 83–96.

Stern, Margaret, Mauricio Quesada, and Kathryn E. Stoner (2002). "Changes in composition and structure of a tropical dry forest following intermittent cattle grazing". **Revista de biologia tropical** 50.3-4, pp. 1021–1034.

United Nations (2011). **Global-Drylands: A UN system-wide response: United Nations Environment Management Group**. Ed. by United Nations Environment Management Group.

Vieira, Daniel L. M. and Aldicir Scariot (2006). "Principles of Natural Regeneration of Tropical Dry Forests for Restoration". **Restoration Ecology** 14.1, pp. 11–20.

Planting trees to provide local wood resources and restore degraded dry tropical forests — Principles, challenges and research needs

University of Hamburg
Institute for World Forestry
Leuschnerstr. 91
21031 Hamburg
Germany