Silviculture and Management in Arid and Semi-arid Regions

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Introduction

Drylands cover 41% of the earth and are represented in all the continents. Insufficient water quantity and in particular inadequate moisture to support plant growth during most of the year characterize these drylands.

Forests and tree formations play important economic, social, and environmental roles in these regions through a variety of functions including:

1. Conservation of soils through the buffering of erosion processes and land degradation control.
2. Conservation and improvement of the quality of water and regulation of the water regime.
3. Reduction of wind velocity, control of wind erosion, and buffering of water and moisture depletion.
4. Influencing local rainfall and condensation.

All these functions are essential and of high value in drylands and for the communities living therein.

The management and silviculture techniques and other human activities essential to the conservation and sustainable development of forests and trees are important but insufficiently documented in drylands. They promote efficient ecological and environmental buffering, and help to mitigate the harsh climatic conditions that characterize drylands. Biological diversity of forests and woodlands in drylands and the physiological functioning that allows their survival under the harsh conditions are conducive to a number of adaptations and processes. These need to be understood so that they may be used as tools underpinning sound silvicultural practices and good management of dry forests.

Arid and Semi-Arid Regions

Drylands 'experience during all or part of the year a period when evaporation exceeds precipitation, a period when all life in such lands must adapt in some way to reduced supplies of water or face death from dehydration.' They are understood generally as being in regions of the earth where the availability of water is deemed unsufficient to respond to the needs of living organisms. In particular, the water supply is insufficient to respond to the needs of human development including all the production activities that transform natural resources into goods and services. Drylands are generally marked by seasonality of rainfall, translating into an unsatisfactory distribution of water and moisture through the year. These elements affect the nature, quality, and distribution of plant life and of forests in particular.

Drylands are defined in terms of water related stress where mean annual rainfall (P) over potential evapotranspiration (PET) is less that the unity: $P/PET < 1$. Drylands are divided into various categories depending on the value of this equation. The greater the difference from 1, the greater the saturation deficit and the greater the stress plant communities are submitted to. The various subdivisions are shown in **Table 1**.

The Food and Agriculture Organization of the United Nations, with concerns mostly related to an effective growth period of vegetation used definitions based on the length of growing period (LGP). The growing period starts once rainfall exceeds half of the potential evapotranspiration. Areas are classified as follows:

- hyperarid (true deserts): LGP less than 1 day
- arid lands LGP less than 75 days,
- (dry) semi-arid LGP 75 to 120 days,
- (moist) semi-arid 120 to less than 180 days.

Overall, drylands cover 61 million km^2 or 40.7% of the total land area of the earth.

Forest Resources in Arid and Semi-Arid Regions: Categories, Location, Extent, State, and Evolution

The *Forest Resources Assessment 2000* estimated the extent of dry forests, mostly in arid and semi-arid areas, at 676 million ha, or 17% of the world's forested area. This covers a variety of formations from woodlands to steppe formations of various

Table 1 Subdivisions of the drylands of the world

Category	*P/PET*	*Percentage of global land area*
Hyperarid lands (usually known as deserts where vegetation is absent or discrete)	<0.05	8%
Arid lands	0.05–0.20	12%
Semi-arid lands	0.20–0.50	18%
Dry subhumid lands	>0.50	10%

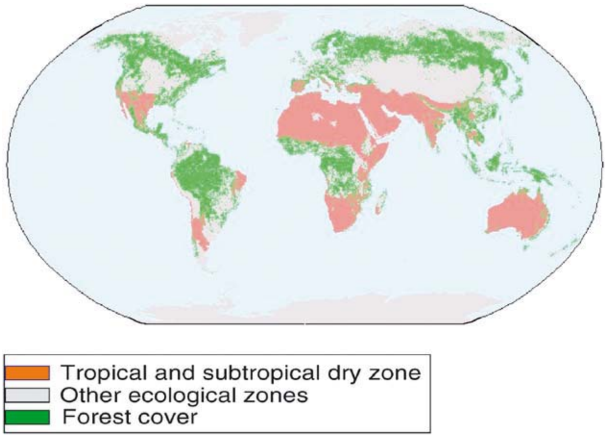

Figure 1 World distribution of dry zones and forest cover. From *Forest Resources Assessment 2000*.

structures and composition, but they occur mostly in the intertropical zones and subtropics (**Figure 1**). (Forests that are dry owing to the unavailability of water because of frost processes are not covered in this section.) Subtropical or Mediterranean forests have the same main characteristics as tropical arid and semi-arid forests: seasonal rainfall with frequent drought periods; structuring and biological influences of forest/bush fires; strong interactions with and mutual influences of agriculture and livestock raising; and the multifarious social and human functions they fulfil.

Categories of Forests and other Wooded Lands in Arid and Semi-Arid Areas

Most of the intertropical dry forests change according to rain and temperature/ecological gradients that run parallel to the equator. Although they share a number of characteristics due to the adaptation of local vegetation (vegetative cycles around and in the warmer and rainy seasons, presence of spines in arid areas, brilliant or velvety foliage, staged and deep rooting, stunted shapes under extreme conditions), these forests differ according to regions and continents. In general, tree presence, cover, and density decrease while grass cover increases regularly from higher to lower rainfall areas and increasing areas of stress. The typological gradient goes from dry deciduous forests to thickets, to open woodlands and savanna woodlands and then to tree savanna, shrub savanna with mixed trees, to thorny shrub steppes. **Figure 2** gives an overview of the arid and semi-arid woody plant formations of the world.

In the forest or woodland formations of arid and semi-arid areas, woody species play important and various functions. They produce small-dimensioned timber of specific and valued characteristics in density, grain, coloration, and resistance, suitable for various uses and applications from luxury wood handicrafts, saw timber to fuelwood and charcoal. Such forests also produce a great amount and diversity of non-wood goods including material for handicrafts, food, gums, resins, honey and wax, feed and fodder which help in the livelihoods of the local communities. Thus they provide vital support, directly or indirectly, for food production, security, health, and amenity.

Extent of Arid and Semi-Arid Forests in the World

Forests of arid and semi-arid areas are designated dry forests in this section. Dry forests occur in the dry, semi-arid, and arid ecological zones in tropical and subtropical regions. Most of them are found in the dry tropics and subtropics (83%). A low percentage of dry forest (17%) is found in the areas characterized by shrubs, steppes and desert formations (**Table 2**).

Economic and Social Importance of Forests in Arid and Semi-Arid Areas

The importance and central role of forest and tree formations in the well-being of populations in dry areas and specifically in arid and semi-arid areas cannot be overemphasized. Populations in arid and semi-arid areas have technologies and practices that use tree and forest resources in many aspects of their livelihoods: dwelling, food supply, clothing, comfort and amenity. In this, timber is a secondary product compared to non-wood forest products.

Direct Food Production

Shrubs and trees provide many food items. These include fruits, nuts, gums, roots and more rarely tubers, an innumerable array of leaves, and flowers. A number of species of particular interest have become internationally traded products such as gum arabic from *Acacia senegal*, setigera gum from the mbep tree *Sterculia setigera* occurring in the African Sudano-Sahelian woodlands and tree savannas, tamarind from *Tamarindus indica* of the tree savannas and woodlands of Africa, Southern America and tropical Asia, the butter from the renowned shea butter tree *Vitellaria paradoxa*, and the various products from the genus *Prosopis* particularly *Prosopis juliflora* of Central and South America. Flowers in dry forests yield excellent honey, pollen, and wax. A host of beverages are brewed from leaves and grasses, e.g., *Combretum* spp., *Vitex*, *Lippia*, and *Vetiveria*.

Dry deciduous forests These formations are at the fringe of semi-arid forests. They derive from subhumid forests with trees around 20 m tall over an understory of smaller trees and shrubs. The grass layer is discontinuous except in openings or clearings.

Thickets These are low formations of shrubs and small trees of 8 m or less. Generally they include shrubby acacias other stunted evergreen species.

Open woodlands As rainfall decreases formations of tall trees (around 20 m) scattered over an understory of smaller trees and shrubs appear in the landscapes of open woodlands. These are strongly wooded formations neither as tall nor as densely populated as forests but whose overall multistory stands cover the soil.

Savannas Dry forests and woodlands generally respond to the agreed definition of forest: 'land with tree crown cover (or equivalent stocking level) of more than 10% and area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 m at maturity.' When woodlands evolve to savannas, grass cover becomes nearly dominant to exclusive. These formations are common in Africa and in the Brazilian *cerrados* and *campos* in South America.

Steppes The steppes have an even more modest tree cover and a discontinuous grass cover. They are however the domain of some woody species of high ecological, economic, and social relevance.

Figure 2 An overview of dry forest and tree formations. After Tropical Forest Botany, CTFT, Tome I, p. 135–139.

Table 2 Extent and distribution of dry forests

Region	Tropical dry forest (ha × 10^6)	Subtropical dry forest (ha × 10^6)	Total dry forest (ha × 10^6)	Percentage of total regional forest	Percentage of total world dry forest
Africa	215 560	7 176	222 736	34	33
Asia	98 178	5 938	104 116	19	15
Oceania	78 535	47 881	126 416	64	19
Europe	0	41 748	41 748	4	6
North and Central America	8 861	15 267	24 129	4	4
South America	147 404	9 850	157 254	18	23
Total	548 539	127 861	676 399	17	100

Data from Forest Resources Assessment 2000 (FAO).

Medicinal and Related Products

Some of the species mentioned above provide medicinal preparations, but many other species of the arid and semi-arid lands produce the active ingredients for medical and cosmetic uses. These products bring cash income into the communities living in the forest and savanna. Many countries in the dry zones of Africa have organized the traditional practitioners and their activities in the formulation and presentation of local medicines. Cooperation has been established with modern medical and health institutions. Species such as *Vitellaria paradoxa*, *Jatropha curcas,* the jojoba (*Schimondsia chinensis*), and many other species exemplify the contribution of plants of dry areas to the production of medicinal ingredients.

Timber, Fuelwood, and Charcoal

Forests and trees of dry areas yield important timber resources but only in limited quantities; hence their sustainable management is important. Due to the heat and water stresses, growth of timber is usually slow. This results in high-value timber in terms of texture, grain, and coloration. Most of the timber is of precious wood for cabinet-making or art handicrafts. Examples include the *Pterocarpus* species such *P. erinaceus* producing the precious Venn timber, the dry-area mahogany (*Khaya senegalensis*), and the ironwood produced by *Dalbergia melanoxylon*.

Wood for various local services (poles, building materials) is also important. But the most pressing use of wood is for energy. In all arid and semi-arid areas the processing and transport of fuelwood or charcoal is an active sector of the local and national economies. The first initiatives in the management of dry forests are aimed at organizing and regulating the supply of fuelwood to consumers, mostly in cities.

Miscellaneous Products for Small Industry Opportunities

Dry forests and other wooded lands of arid and semi-arid areas are sources of various products which play key roles in the livelihoods of local communities. A rich and diversified set of traditional technologies have made use of them. Today they are often the basis of small family enterprises contributing to fighting poverty. Processing of nuts, drupes, and beans (e.g. of *Balanites*, *Ziziphus*, *Parinari*, *Parkia*, and *Borassus*, to note some examples from dry West Africa), provides trade opportunities beyond village consumption to medium and large cities and to regional and international markets (**Figure 3**).

Figure 3 Various locally manufactured products from non-wood forest products in a dry region of West Africa. Courtesy of FAO.

Wildlife, Game, and Recreation

Arid and semi-arid zones are rich in wildlife and spectacular landscapes. This is an interesting area that forest management cannot ignore but which has not up till now been appropriately taken into account. It has been dealt with in protected areas and game reserves, but in terms of international tourism and hunting. However, in the African woodlands and savannas antelopes and gazelles, (e.g., *Tragelaphus scriptus*, *Gazella rufifrons*, and *Cephalophus* spp.), as well as many small rodents, can provide protein for the diet of the local population. Warthogs and larger antelopes in the more subhumid areas offer opportunities for hunting and tourism. The spectacles of myriad of birds local or migratory in wet areas and water points are also excellent features, which benefit conservation and tourism activities. The criteria for sustainable forest management developed in all dry forest zones include conservation of biological diversity and it is expected that greater attention will be devoted to this in future.

Support for Agriculture

Dry forests are areas of major human development. Agriculture has had maximum development in semi-arid tropical and subtropical regions and at present they continue to play major roles in providing food in these areas. Forests and tree formations are a ready source of agricultural lands, and countries where rates of deforestation have remained high have lost these forests to agriculture. In the Sudan, hundreds of thousands of hectares of *Acacia seyal* forests have been lost to extensive sorghum cultivation; most of the annual loss of 900 000 ha of forest and other wooded land in this country between 1990 and 2000 was from the semi-arid and arid areas. The same situation prevails in all dry tropical countries. In the Mediterranean region pressures on forests for agriculture are very limited, except where irrigation systems can be extended. Indeed most suitable dry lands have been already occupied. Pressures may remain high in Asia and Latin America.

Fodder Production and Animal Husbandry in Pastoral Communities

Arid and semi-arid lands provide range areas *par excellence*. Throughout the world, people in these areas have built their livelihoods on the intimate knowledge and use of plant communities. A substantial corpus of traditional knowledge on the multifaceted role of the woody and grass vegetation of drylands has been developed. Very specialized modes of utilization have been developed, as shown in the example in **Table 3**.

Amenity

Species of arid and semi-arid areas are usually slender, with symmetrical canopies and often beautiful flowers. Some offer much needed shade in hot areas or may constitute efficient windbreaks to buffer heat and check dust. Some *Acacia* species, *Bauhinia*, *Cassia*, *Combretum*, and *Prosopis* are beautiful trees with magnificent flowers (**Figure 4**). Some species of worldwide importance include *Dichrostachys* spp., *Bauhinia*, some *Cassia* (e.g., *C. sieberiana*); and a number of *Cactus* species. The development of urban and peri-urban forestry has used species such as

Figure 4 A blooming *Combretum lecardii* in the dry season in the Sudano–Sahelian zone. Photograph by E Sène.

Table 3 Species utilization in the livelihood systems of dryland communities in the Sahel of Senegal

Objective	*Species used*
Animal nutrition	
For lactation	*Grewia bicolor*, *Acacia radiana*, *Acacia albida*, *Adansonia digitata*
For fattening	*Acacia radiana*, *Acacia albida*, *Acacia senegal*
Medicinal/veterinarian purposes	*Adansonia digitata*, *Adenium obesum*, *Acacia nilotica*, *Combretum glutinosum*, *Combretum micranthum*, *Combretum aculeatum*, *Crataeva religiosa*, *Bauhinia rufescens*, *Grewia bicolor*, *Dichrostachys cinerea*, *Cadaba farinosa*, *Balanites aegyptiaca*, *Sclerocarya birrea*, *Salvadora persica*
Construction	*Balanites aegyptiaca*, *Acacia nilotica*, *Prosopis africana*, *Hyphaena thebaica*, *Borassus aethiopum*

Parkinsonia spp., *Prosopis*, *Tamarindus indica*, and a number of Australian species including dry-area eucalyptus and acacias (e.g., *Acacia bivenosa*, *A. holosericea*, and *A. tumida*), *Prosopis*, in particular *P. juliflora* and *P. chilensis*, *Tamarix* spp., etc.

Biology of Dry Forests, and their Silviculture

Ecology of Arid and Semi-Arid Areas

The biological and physiological characteristics of the vegetation of arid and semi-arid areas guarantee adaptation to great heat and light, the inadequate availability of water, and, in a number of cases, salinity. In many cases the highest temperatures correspond to periods when availability of water is lowest which significantly increases stress in plant communities. A number of characteristics and attributes of these plant communities will be strong tools for the silvicultural treatment of forest and tree formations. The following should be particularly retained:

1. Protection and mobility of seeds. Most seeds are efficiently protected either by a long dormancy or a physical barrier to moisture, comprising a cuticle which needs to be altered chemically or mechanically before germination. Thus, seeds eaten by animals may benefit from partial modification of the cuticle, which later facilitates germination far from their origin. Other seeds (e.g., *Pterocarpus*) have wings or light tufts that facilitates transportation by wind.
2. Structure and functioning of the root system. The root systems of plants in arid and semi-arid areas are the strongest tools for their adaptation, survival, and regeneration. Most of them are deep with a taproot, which can extend to more than 10 m below ground. They have, in addition, extremely well-developed superficial horizontal roots (**Figure 5**), which can explore both for nutrients and moisture from the upper layers of the soil. Often roots develop suckers when they are slightly damaged or after fires.
3. Sprouting and protection of shoots. Many arid area species sprout vigorously and abundantly. The initial vitality of the shoots may facilitate survival through part of the dry season. These shoots have a number of adaptative options (stunting, early formation of thick bark, survival through shedding the aboveground part of the stem, and strengthening of underground organs) that guarantee final survival.
4. Reduction of leaf surface area. A relatively small leaf surface area helps dry-zone species overcome stress and maintain limited functions during the dry season.

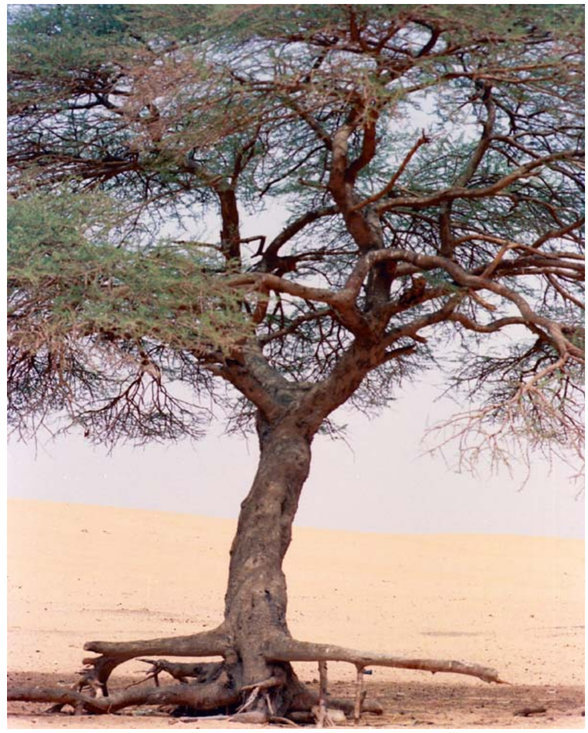

Figure 5 Rooting system of *Acacia*. Photograph by E Sène.

5. Other flexible biological adaptations. Grasses and some shrubs develop a number of other adaptations, producing, e.g., bulbs, voluminous rootstock (*Guiera senegalensis, Icacina* spp.) which not only guarantee survival but also facilitate dissemination.
6. Adaptation to salinity. Many species are able to grow on saline soils or resist rising salinity. They adapt through evaporation and deposition of the salt on the leaves which are protected by leaves becoming succulent (*Dodonea* spp.) or very thin (*Tamarix* spp.).

It is only through these various adaptive strategies that plant formations succeed in living nearly unnoticed during dry periods and indeed are able to bounce back with speed and vigor as soon as rains occur. The silviculturist will use these adaptative strategies to trigger and manage regeneration.

Silviculture and Dry Forests

The corpus of knowledge supporting silviculture in arid and semi-arid forests is still to be largely completed. Some of the elements on which silviculture of these ecosystems are based are reviewed below.

Climate and seasonality The general pattern in drylands features the existence of strongly marked seasons. The dry season, of variable length according to the region, subjects living organisms to strong stresses. They are usually accompanied by the loss of foliage, to reduce evapotranspiration. Species adapt in a number of ways: spines, coated or velvety leaves, thick bark. This period is also marked by fires which debilitate the forests, kill seedlings, and when occurring late in the cycle destroy flowers and fruits. This may influence the livelihoods of populations as their strategy includes the use of fruits that mature in dry seasons (e.g., *Cordyla*, *Parkia*, *Ziziphus*) for lean periods. It may, by contrast, facilitate germination when the rainy season comes. Managing forest fires is then a potent tool in the management of dryland forests.

The unpredictability of the onset of the rains, the occurrence of large spells of drought during the rainy season itself or its precocious end are factors that strongly affect the growth and vitality of the forest in drylands and which make more difficult the silviculture of these forests. Fire hazards and the spread of insects will be highly dependent on such factors.

Heat and moisture are other important factors affecting the vitality of the forest. Temperatures in drylands may reach very high levels. In the Africa Sudano-Sahelian and Sahelian zones they are over 30°C for most of the year. In some periods high temperature and low humidity combine to produce high stress. These periods are the ones that most influence survival and the physiognomy of arid and semi-arid formations. When biological activity is at its lowest logging and other silvicultural operations may best be carried out.

Land and soils In most semi-arid regions, the most valuable land is devoted to agriculture. Forestry is reserved for poorer lands. In arid areas livestock rearing is dominant. But forests and tree formations have other important roles to play. Organic matter is in short supply in dryland soils. In forests and other wooded lands, which should play important roles in producing organic matter, mineralization is extremely quick. The grass biomass, however, contributes much to the process and should be incorporated into soils as early as possible. This prevents the export of much of the moisture when the climate dries up. Plantation silviculture needs to take this into account through well-planned seedling production campaigns, thorough soil preparation practices optimizing the relatively small amount of rainfall, adequate timing of planting operations, and weeding.

Human and social environment The dependence of local communities on the forest and tree resources is very high in arid and semi-arid areas. Stabilized agriculture takes place mostly in valleys and other topographically suitable areas with a high water table. Rain-fed agriculture is linked to the removal of the forests where some organic material has been accumulated under fallow or as new land. Pastoral land use is pervasive and forests and other wooded lands are the main resources supporting livestock. Silviculture as well as agriculture withstands competition with animal husbandry, but the control of livestock movements will be an important prerequisite in any forest management option. The utilization of a host of non-wood forest products is characteristic of dry forest use. This entails an intimate interaction of people and forests which can have a strong impact on silviculture and forest management.

Options for Silvicultural Models in Arid and Semi-Arid Forests

Silvicultural operations have a number of major functions, including structuring the stands; boosting growth and favoring selected stems; enhancing non-wood production, in particular fodder; securing health and vitality; and assisting regeneration. Generally, dry formations include separate or combined grass layers, bush and thicket, and intermediate small trees between taller trees. Silvicultural operations will aim at:

- controlling grass for proper use and avoiding its unplanned burning
- clearing or structuring the thicket to make it 'user friendly' and easy to enter
- maintaining the intermediate trees as a balanced filling to respond to needs for wood for fuel and service (usually by coppicing)
- dealing with biotic interferences, especially protecting regeneration from browsing by livestock or wild animals
- maintaining at long rotations the 'high forest' component often made up of species of high value.

Objectives usually cover (1) conservation and protection; (2) multipurpose production; (3) fuelwood production; and (4) timber production. As in all silvicultural regimes the regeneration methods and objectives govern options in dry forest silviculture. Dry forest formations can be regenerated through seeding and planting and through a series of vegetative regeneration practices. The regeneration methods are summarized below.

Natural regeneration Natural regeneration is constrained by many factors. Most fruits and seeds mature at the end of the rainy season or just before it. Seeds are very difficult to conserve when they are fleshy or if they are difficult to germinate. Fleshy seeds germinate very easily with the rains (e.g., *Sclerocarya birrea*, *Cordyla africana*) provided the soil is not hard or glazed. Unfortunately the seedlings have to face immediate competition from grass and other plants and the difficult survival conditions of the dry season. The risk of fire is high and most probably with no particular protection a very limited number of seedlings survives. There is also the risk of seedlings being eaten by wild or domesticated animals. Seeds with hard coats may lie dormant and resistant to mild natural processes and germinate only under particular natural processes or guided assistance provided by the silviculturist. The ingestion of fruits and seeds by animals including birds is important in the natural regeneration process. The digestion process alters the seed coat and facilitates germination (this explains the clustered nature of trees in *Acacia* savannas and steppes.)

Assisted natural regeneration Silvicultural interventions to assist and enhance natural regeneration are indispensable. They will aim at (1) easing water percolation and storage through subsoiling, ridging, and creation of structures where seeds and water preferentially accumulate; (2) reducing competition from grasses and shrubs with timely weeding; and (3) protection from fire either through complete weeding, partial weeding around the seedlings, and establishment of fire breaks.

Vegetative regeneration Usually species of dry areas react well to vegetative stimuli through sprouting, layering, cutting, and suckering. Vegetative regeneration is the most common basis of silviculture. Stands are regenerated after logging as most species sprout very strongly, thus providing stems that are appropriate for fuelwood or for making posts. Medium to superficial subsoiling may be used to scar roots and enhance regeneration through sucker inducement (e.g., most *Acacia* species, *Balanites aegyptica*, *Daniella olivieri*, *Cordyla pinnata*, and a number of miombo species).

Silvicultural Regimes

The coppice system Production of fuelwood and posts is the major objective of dry forest management. In West Africa it is in the production of fuelwood from the mix of Combretaceae and Leguminosae (mostly *Acacia*), with a filling of *Detarium macrocarpum* that management has evolved. These constitute the bulk of woodland stands. Pure stands sprout after logging. Cases in point are stands of *Combretum* and *Anogeissus*; pure stands of *Acacia seyal*; and partially inundated valley stands of *Acacia nilotica*.

Coppice and standard system In many types of dry forests and woodlands dominant trees are species of high value that are not used for fuel but for timber (*Khaya senegalensis*, *Pterocarpus erinaceus*, *Detarium* spp.) or fruit production (*Parkia biglobosa*, *Cola cordifolia*, *Sclerocarya birrea*). The same approach is valid for the miombo woodlands. Smaller trees and shrubs are periodically clear-cut, mostly for fuelwood and charcoal. This treatment is a coppice-with-standard system with different objectives pursued through the two components.

High forest system Pure high forests originating from seedlings are seldom established in dry regions. However under some special stand conditions pure stands can exist and naturally regenerate. A number of *Acacia* species are gregarious and may develop sizeable pure stands. Examples are *A. seyal*, *A. senegal*, and *A. nilotica* associated with floodplains or low-lying lands. In Central and southern America, *Prosopis juliflora* and *P. tamarugo* grow usually in thick pure stands, naturally regenerated. With the potential of abundantly producing suckers, some species produce pure stands with the appearance of seedling originated natural regeneration. *Daniella oliveri* in West Africa is an example. Silvicultural operations may choose to take advantage of these special situations, but then sprouts and suckers may overtake seedlings and most of apparently seed generated communities may well have derived from vegetative propagation.

Plantations Plantations in arid lands raise many problems but may be the only option when needs are urgent, or when rehabilitation and restoration are essential. Considerable efforts have been made in creating new forest plantations in some countries. There are 14 countries in the dry zones that have large planted forests. They include India, Thailand, Iran, Turkey, South Africa, Australia, Pakistan, Algeria, Sudan, Argentina, Chile, and Spain. These countries account for around one-third of the world's planted forests as estimated in the FAO's *Forest Resources Assessment 2000*.

Economic considerations Silviculture and management of forests succeed only if the operations engaged are sustained throughout the cycle of the forests. The initial investment in partitioning the forest and the subsequent operations of maintenance, thinning, and intermediate cutting call for financial resources. These are not always readily available with neither national forestry institutions nor local or private entities and individuals as investors. Options should be low in external and capital inputs and reasonably labor intensive. Foresters in many dry areas have promoted community-driven forest management and efforts on efficient marketing of products from managed forests (*see* **Social and Collaborative Forestry:** Joint and Collaborative Forest Management).

Managing Dry Forests for Various Objectives

Specificity and General Objectives of the Management of Dry Forests

Dry forests have to meet diversified economic, social, and ecological needs. The management of dry forests aims at (1) assessing societal needs; (2) measuring the resources and their potential, and (3) prescribing programs and operations to satisfy the needs, while securing conservation of the major characteristics of the resources. This is common to all types of forests, but dry forests are strongly constrained by low water availability, drought spells, forest fires, and strong human needs and expectations. Managing dry forests will respond to the needs for timber, wood for energy, a host of non-wood forest products, conservation and utilization of wildlife, recreation and overall conservation of the unique genetic and biological diversity present in them. Management includes a range of options corresponding to: (1) conserving and using sustainably naturally occurring formations; (2) cultivating coppice and high forest trees for differentiated production; (3) planning, organizing, and effecting active renovation of stands through reforestation; and (4) planning and effecting afforestation on bare land. A number of activities where trees are mixed with other land uses can be associated with forest.

History in the Management of Dry Forests

Until the early 1950s in many dry areas forestry was focused on conservation. Then initiatives for plantations started to grow, initially with no clear set objectives. Forest management started with very simple goals in many cases, aiming at securing fuelwood supplies for rail companies or for small industries such as brickmaking or cane alcohol distillation. But by the early 1980s, overconsumption of fuelwood and initiatives concerning renewable energy resources had brought attention to the potential of forest management to secure sustained supplies and conservation of resources. Programs of management of native forests instead of plantations were later promoted by aid donors, and by the early 1990s a number of demonstration projects had been completed allowing lessons to be drawn and targeted extension work to be developed. Countries such as Burkina Faso, Niger, and Madagascar in Africa began to develop national programs of forest management.

Promoting Sustainable Management of Dry Forests

The Intergovernmental Panel on Forests/Intergovernmental Forum on Forests program of action has addressed the issue of criteria and indicators for sustainable management of dry forests in Africa, Asia, and Latin America. A set of internationally accepted thematic areas corresponding to the following seven criteria for sustainable forest management have been agreed upon:

1. The extent of forest resources.
2. Biological diversity of the forests.
3. Forest health and vitality.
4. Productive functions of forests.
5. Protective functions of forests.
6. Socioeconomic functions of forests.
7. Legal, policy and institutional framework.

Forest management and silviculture should aim for the realization of these criteria that cater for the new paradigms of sustainable development.

Defining and protecting forest status/extent in arid and semi-arid areas At international level, FAO estimated that in developing countries dry forests, which covered 238.3 million ha in 1990, were being lost at the rate of 2.2 million ha per year in the period 1980–1990. This represented 1.1 million ha in Africa, 0.5 million ha in Asia, and 0.6 million ha in Latin America. *Forest Resource Assessment 2000*, estimated dry (tropical and subtropical) forests at 374 million ha. At national level maintaining the forests is a great challenge for dryland countries with growing populations and rampant poverty. Many countries now encourage the populace to get organized and engage in forest management as full partners.

Conserving the biological diversity of dry forests The multifunctional characters of vegetation from arid and semi-arid areas underlines the need for the conservation of the genetic resources they contain. Many efforts have been devoted to this and the multipurpose woody species of arid and semi-arid regions have been the subject of many projects on forest genetic resources. The Convention on Biological Diversity has reserved particular efforts to defining a program on the biological diversity of drylands, Mediterranean, arid, semi-arid, grassland, and savanna ecosystems. FAO has promoted national and regional projects for the conservation and use of the genetic resources of woody species of arid and semi-arid zones in Africa, Asia, and South America. A number of countries from the arid and semi-arid regions have recently developed national forest seed centers supporting growing afforestation programs. Ecosystem conservation is active in arid and semi-arid regions in response to their rich animal biological diversity, but more efforts are certainly needed.

Health and vitality of semi-arid and arid forests The greatest challenge to the management and protection of forests and woodlands of arid and semi-arid areas is the prevention and control of forest fires. Forest and/or range management should intimately encompass fire management. This will entail where possible methods of early burning in semi-arid forests, forest protection work in areas with high asset values, and population sensitization, training, and organization. The most efficient measures are those that create assets for people in and close to the forests through sustainable use of pasture, wood, bee-keeping operations, etc. Pests and diseases may cyclically break out and careful monitoring is essential.

Maintaining and heightening the protective functions of forests in arid and semi-arid areas It is essential that the management models of forests enhance the role of forests, trees, and grass formations in controlling land degradation, especially through limiting water loss, controlling wind erosion, and improving nutrient intake in soils. A number of species such as *Acacia albida* and *Prosopis procera* are known to improve and maintain soil fertility and moisture content of soils. The ability of, e.g., *A. albida* to conserve its foliage during the dry season and hence attract livestock and other animals under its shade is used in the agroforestry parklands and farming systems in dry regions. Efforts are being made to manage woodlands in watersheds (Guinea, Fouta Djallon, the Volta watershed in Ghana, etc.) to protect headwaters and secure steady flow to the major rivers in West Africa.

Productive and socioeconomic functions of forests The productive and socioeconomic functions of dry forests are closely linked (**Figure 6**). Silviculture and forest management should enhance them. The productive capacity of the resource is however limited. While some woodland and wooded savanna could yield wood products up to $8\,m^3\,ha^{-1}\,year^{-1}$, dry shrub savanna and steppes yield less $1\,m^3\,ha^{-1}\,year^{-1}$. Information on yield is fragmented and of various reliability; it needs to be further documented.

Legal, policy, and institutional framework of dry forest management Forest management needs continuity and monitoring to learn the lessons of experience and to consolidate options, techniques, and practices. In most arid and semi-arid areas the institutional framework for forestry is weak or strongly dependent on other sectors. Laws and regulations may be obsolete. During the last decade, however, sustained efforts have been made to strengthen national institutions and to update legislation and regulations. Efforts to involve local communities in forest management and the work of a number of networks have advanced decentralized models of participatory forest management, mostly in dry areas. The post-Rio Conventions, in particular the Convention to Combat Desertification, have provided new opportunities for institutional strengthening for overall natural resources management in dry areas.

Figure 6 A women's cooperative group in Nazinon forest, Burkina Faso.

Practical Experience

Experiences at country level have closely followed international developments in incorporating progressively current and emerging paradigms in forest management. Among those most important are (1) the devolution of the resources to people and putting forest at the service of local community development; (2) developing and disseminating the concept around the link of forests, trees, and people; (3) managing forest to enhance the multiple functions they support and following agreed-upon criteria and indicators for sustainable forest management in dry areas.

At the start of the twenty-first century, it is difficult to assess overall progress in effective forest management. The *Forest Resources Assessment 2000* of the FAO showed that for developing countries engaged in forest management, out of a total of 2139 millions ha, at least 123 millions ha or about 6% were covered by 'a formal, nationally approved forest management plan.' This shows that efforts are still inadequate. The situation is not much worse in arid and semi-arid areas taking into account the greater involvement of populations in participatory forest management in those areas. In Africa 4% of the dry forests of countries covered by the *Forest Resources Assessment 2000* study on forest management are under some management plan; in South America only 2% are under a management plan.

Challenges Ahead

There are daunting challenges in the management of forests in arid and semi-arid areas which will need to be faced in a sustained and continued way. They include, among others, the following:

1. Raising awareness on the many functions goods and services provided by dry forest resources, to communities that are among the poorest in the world.
2. Strengthening institutions that deal with dryland ecosystems, in particular research and policy institutions at national and regional levels.
3. Increasing knowledge and expanding technologies about assessment, management, conservation, and use of arid and semi-arid forest and tree resources.
4. Continuing work and strengthening cooperation on the assessment of the social, economic, and environmental services of dry forests.
5. Further focusing work on criteria and indicators for sustainable management of dry forests towards effective application and development on the field including considerations of wood and non-wood products of forests of arid and semi-arid zones.
6. Supporting effective action on the field so as to apply the wealth of knowledge acquired and paradigms developed to the sustainable management of forest and tree resources of dry areas.

See also: **Genetics and Genetic Resources**: Forest Management for Conservation. **Medicinal, Food and Aromatic Plants**: Medicinal and Aromatic Plants: Ethnobotany and Conservation Status. **Silviculture**: Managing for Tropical Non-timber Forest Products. **Social and Collaborative Forestry**: Common Property Forest Management; Forest and Tree Tenure and Ownership; Joint and Collaborative Forest Management; Public Participation in Forest Decision Making; Social and Community Forestry; Social Values of Forests. **Tree Physiology**: Stress. **Tropical Forests**: Tropical Dry Forests.

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Silviculture in Polluted Areas

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Introduction

The influence of industrial pollution on forest health has long been recognized as a serious applied and scientific problem. Although numerous field experiments have been established to determine practical measures for both the alleviation of pollution impacts on stand vitality and the rehabilitation of damaged forests, a general strategy has not emerged, and 'silviculture in polluted areas' is still in the incipient stages of development. Maintenance of forests in polluted areas requires more intensive management than in unpolluted areas, involving 'soft' techniques and highly skilled manual labor.

The prescriptions that form the basis of silviculture in polluted areas should be preventive, aimed at improving the ecological stability of stands in such a way that they will better resist pollution impacts. In many cases the vitality and productivity of forests affected by chronic acidification and heavy-metal contamination can be maintained by chemical amelioration. However, to be successful, the revitalization strategy should first aim at identification of nutritional disturbances and then apply diagnostic fertilization to alleviate these disturbances, balancing the anticipated beneficial and adverse effects. Suggested silvicultural measures include the creation of substitute stands, maintenance of stand integrity, a decrease in rotation time, avoidance of monocultures, and replacement of clear-cuts by selective logging and gap-oriented regeneration. The practical application of silvicultural measures, with successful amelioration of pollution impacts, is still limited to a very few areas of boreal and temperate forests.

Polluted Forests: Past, Present, and Future

Pollution, Polluters, and Pollutants

Historically, sulfur dioxide was the first pollutant to cause local but severe forest deterioration. This is the best-studied pollutant, under both experimental and natural conditions. In high concentrations it causes acute foliar damage, which weakens and then kills the trees; in low concentrations it contributes to regional acidification. Conifers are generally more sensitive to SO_2 than broadleaved species.

Fluorine emissions to the atmosphere started to increase in the late 1930s, reaching peak values in the late 1960s. These emissions were primarily associated with aluminum production, and they caused severe but local forest damage. However, fluorine emissions strongly decreased between 1970 and 1980 due to effective measures taken to minimize the release of fluoride from aluminum smelters to the atmosphere.

Heavy metals are very common pollutants but in general do not spread far from smelters. Only some of the largest polluters have caused detectable contamination of soils and vegetation at distances exceeding 50 km from the emission source. Heavy metals emitted by Monchegorsk and Norilsk can be detected (in atmospheric aerosols) and identified (e.g., attributed to the specific polluter) at distances up to 2000 km from the polluter. However, these long-transported metals have never been said to cause any biotic effects, especially in forests. Although most heavy metals are extremely toxic, they have rarely been reported as a cause of forest death. However, heavy metals adversely affect seedling establishment, thus hampering the natural revegetation of contaminated areas long after any decline in atmospheric pollution levels.

Increased deposition of nitrogen started to play an important role in European forests several decades ago. Although this pollutant does not create the dramatic landscapes of some other pollutants, its effects are insidious and long-lasting. In some countries, such as the Netherlands, annual deposition of nitrogen in the late 1980s reached $200\,\mathrm{Kg\,N\,ha^{-1}}$, making eutrophication more important than the impact of 'traditional' pollutants. Increases in N deposition are also a big issue in some parts of North America, such as the San Bernardino Mountains of California.

Finally, ozone was recently identified as a possible contributor to forest damage in Europe and North America. Although unequivocal evidence for O_3-induced foliar injury on woody species under field conditions has only been found in a few places, mostly in regions with a warm and sunny climate (the Mediterranean, south California), and in alpine areas, including Sierra Nevada and the Appalachian mountain chains, ozone obviously weakens the trees leaving them vulnerable to other assaults and stresses. Overall, the quantitative risk assessment of O_3 impact on mature trees and forests is uncertain at the