Chapter

Pinus patula Plantations in Africa: An Overview of Its Silvicultural Traits and Use under SDG

Wubalem Tadesse and Teresa Fidalgo Fonseca

Abstract

Pinus patula Schiede ex Schltdl. & Cham. is a forest tree species native to Mexico, widely cultivated in tropical and subtropical regions of the world. In Africa, the plantation of the species has gained considerable interest being represented in different African countries, and probably being the most widely planted pine in tropical Africa. The species traits and the diversity of wood use to highlight the importance and usefulness of the species in the tropical regions of the African continent. The aim of this chapter is to review the state-of-the-art on the knowledge of the species, namely their characteristics and their growth dynamics, present information on productions, silvicultural management and biotic vulnerabilities, and summarize the effects on biodiversity and relevance on carbon stock. Knowledge of species biological and silvicultural traits supports decision-making on sustainable forest management and contributes to the achievement of the Sustainable Development Goals of UN Agenda 2030.

Keywords: Patula pine, species traits, silviculture, forest sustainability, afforestation

1. Introduction

About 1/3 of the world's total land surface is forest (4.06 billion hectares). In terms of major regions, the forest area in America represents 40% of the total (21% for South America and 19% for North and Central America), Europe contributes 25%, followed by Africa, with 16% of the world's forested area. Asia has 15% and Oceania has the remaining 5% [1]. The importance of forests is widely accepted and is addressed in the UN 2030 Agenda for Sustainable Development, being broadened and considered in Sustainable Development Goal (SDG) 15—Life on Land [2]. The agenda is a commitment of the United Nations to eradicate poverty and achieve sustainable development by 2030 worldwide, ensuring that no one is left behind. Forestry can help to achieve SDGs, especially SDG 15 which specifically considers to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss [2], but also SDG 1 (income to fight poverty) or SDG13 (carbon capture and storage) among others. See Baumgartner [3], for a comprehensive discussion on how sustainable forest management could contribute to achieving other Sustainable Development Goals.

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Global Forest Resources Assessment 2020 report [1] informs that the world has lost a net area of 178 million ha of forest since 1990, with the highest annual rate of net forest loss in 2010–2020 occurring in Africa (net forest loss of 3.9 million ha). The same source [1] reports that the rate of net forest loss has increased in Africa in each of the three decades since 1990. Forest resources have paramount socioeconomic and ecological importance in many African countries. They contribute to poverty alleviation in a variety of ways and provide important support mainly for sub-Saharan Africa's economic, social, cultural, and environmental development, especially in rural areas. Over two-thirds of all Africans rely directly or indirectly on forest resources for their livelihoods. However, deforestation and forest degradation are hampering the forest resources of many countries in the continent. These forests have come under severe pressure from a growing demand for forest products, particularly fuelwood, and the expansion of agricultural land. The use of planted forests is a strategy that supports and benefits the achievement of SDG 15. To this end, knowledge of the biological traits and silviculture of forest species and decision on what appropriate species to use is essential.

With this review, the authors aimed to gather information on one of the most widely used species in plantations in Africa, *Pinus patula*. The literature on the species is considerable but is rather limited when restricted to Africa. The information here presented intends to provide guidance on the use of this species as a management option to consider when the aim is to ensure the sustainability of forest resources on this continent.

2. Distribution and ecology of *P. patula*

P. patula Schiede ex Schltdl. & Cham., commonly known in English as Mexican weeping pine or patula pine, is a native species from Mexico [4, 5]. The species is largely used for plantations in tropical and subtropical regions of the world, including South America, Central and Southern Africa, Indonesia, Australia, and New Zealand [6 and references herein]. The area planted with *P. patula* worldwide is approximately 1 million hectares, of which 95% correspond to plantations in Central, Eastern, and southern Africa [6]. It is widely planted in different African countries. Probably is the most widely planted pine in tropical Africa. **Figures 1** and **2** present a *P. patula* plantation in Ethiopia. The species is of particular importance in Kenya, where it accounts for about 25% of all forest plantations. It is also important species in Madagascar, Malawi, South Africa, Tanzania, and Zimbabwe. For instance, in South Africa, 54% of the total forested area is pine forest, with *P. patula* being the most widespread species, covering an area of about 375,000 ha [6].

P. patula is a species that tolerates most soils and will grow in grassland. The species thrives best when there is good water supply but can also overcome unfavorable conditions [7]. It is often found in pure dense stands, but the occurrence is discontinuous, and now, for much of its range, it develops only in areas inaccessible to agriculture. Over its entire distribution range, *P. patula* can be found associated with *Platocthispa gregorii* and *P. teocote*, with which it is said to have hybridized. Other mixtures mentioned include association with *P. montizumae* and *P. rudis*, *Abies religiosa*, *Taxus mexicana*, and hardwood species of such genera as *Acer*, *Cercis*, *Fagus*, *Tilia,* and *Liquidambar* [7]. *P. patula* demands deep, well-drained soils and grows best in the mist belt regions of South Africa above 1 000 m elevation. In southern Africa, the species are generally planted in areas with mean annual temperatures below 17°C [8]. In Ethiopia, the species develops best with good water supplies but can also survive adverse conditions in 1900–3000 m [9].



Figure 1.
Pinus patula *plantation picture in south West Ethiopia (photo credit: Reinhold G).*



Figure 2.
Pinus patula *plantation picture in Western Ethiopia (photo credit: Wubalem Tadesse).*

In southern Africa female flowering starts when trees are 2–3 years old, and male flowering 1–2 years later. The flowering of both male and female cones occurs in August–October, with usually a secondary flush of only female cones in January–May. In Kenya, two flushes of male and female flowering normally occur in April–May and October–November, coinciding with the rainy seasons. However, there are also records of female flowering happening throughout the year. Studies in Zimbabwe showed that synchronization of pollen shedding and female receptivity was good at 1500 m altitude, whereas pollen shedding occurred progressively later at lower altitudes. Outcrossing is predominant, and pollination is mainly by wind. Female cones mature in 22–30 months. The production of viable seeds starts when trees are 5 years old, and is prolific in 8–10-year-old trees. Seed dispersal is usually by wind, but sometimes also by birds, rodents, or people [5].

P. patula is a very demanding species in terms of light. It is considered an aggressive pioneer species that grows easily in forest gaps created by fire. In countries, such as South Africa, Swaziland, and Zimbabwe, it is now considered a serious weed, forest edges, moist grasslands, and road cuts [5].

3. Silvicultural characteristics

3.1 Tree species characteristics, growth dynamics, and yield

P. patula grows very fast. Under favorable conditions, it may attain a height (h) of 15 m after 8 years and 35 m after 30 years [5]. The species can reach a diameter at breast height (d) of up to 1.2 m [7]. The bole is usually straight and cylindrical (see **Figures 1** and **2**). Sometimes the trunk fork produces two or more stems. When the growing area of the tree is large (wide-spaced plantation), the crown tends to spread out. In terms of shape, the crown can be rounded or spiral-shaped. The bark has distinct characteristics depending on the tree's stage of development. When young, it has a reddish-orange color and is scaly. In contrast, the mature bark is gray-brown and vertically ridged [7].

Mean annual increments in volume (MAI) are 10–40 $m^3ha^{-1}y^{-1}$, in southern Africa ranging from 18 to 28 $m^3ha^{-1}y^{-1}$. In East Africa, the species can show higher yields than in southern Africa due to a shorter dry season. The total yield (including thinning removals) under appropriate conditions maybe 630–700 m^3ha^{-1} [5]. In South Africa, when planted on sites with well-drained soils, mean annual temperatures below 17°C and at altitudes above 1000 m, the species has an expected MAI ranging from 10.9 $m^3ha^{-1}y^{-1}$ to 27.2 $m^3ha^{-1}y^{-1}$, good stem form, and wood properties [10].

According to the Wood Data Base [11], this species presents a wood density of around 450 kgm^{-3} (dried basis) and 580 kgm^{-3} (12% of moisture). Wood density may vary depending on the altitude, presenting higher values when plantation occurs at lower altitudes, instead of higher ones. The length of rotation also influences wood density. In Tanzania, density at 12% moisture content was reported to increase from 380 kgm^{-3} for 12-year-old trees to 510 kgm^{-3} for 30-year-old trees [5]. *P. patula* is mainly used for firewood, timber (boxes, general purpose), posts (treated with wood preservative), pulpwood, shade, and ornamental [7]. The wood is highly appreciated for glued laminated timber for carpentry and furniture after the knots have been removed. It is also suitable for hardboard, particleboard, and wood wool. *P. patula* is an important source of pulpwood [5].

3.2 Silvicultural guidelines

The species is used in forestation and afforestation as a high-forest managed system, with an even-aged stand structure (see **Figures 1** and **2**). Although mixtures can be found (see Section 2), typically, *P. patula* is managed in pure stands.

Initial spacing for *P. patula* in most countries is from about 2.4 m to 2.75 m or 3 m, corresponding to individual growing areas around 6–9 m^2. Generally, for sawlogs, closer spacing is recommended for knot-free wood. Wider spacing is recommended on poorer sites. Sawlog regimes in common use are conceived to have about 250 $treesha^{-1}$ with an average diameter at breast height of 45 cm at a 45-year rotation. For pulp schedules, rotations range from 15 years in Swaziland to 25 years, as recommended in South Africa [7].

During the first year after planting 2–3 operations to control spontaneous vegetation are required, to reduce the occurrence and growth of competitive vegetation and optimize yield. Ndlovu et al. [10] referring to the species grown on pulpwood regime, point out the importance of vegetation management impacts, vegetation management, by keeping the stands free of vegetation, showing a positive significant influence on diameter at breast height, basal area, and volume growth, with implications on rotation end stand volume. The vegetation management is performed through manual removal or chemically with the application of glyphosate.

The response of *P. patula* to fertilizers is site-specific, with some research studies pointing to the beneficial effect of phosphorus and potassium fertilizer in stand growth [12, 13] and in correcting the growth decline observed between first and second rotations [14]. Results by [15] support the beneficial effects of phosphorus but not nitrogen on the early growth of the species. The application of N significantly depressed the diameter growth of the trees.

P. patula is a species with limited self-pruning, justifying the use of artificial pruning, to reduce the risk of fire and improve access within the stand ("low pruning"). In general, trees are pruned at 4–6 years of age to a height of 2.5 m. In pulpwood plantations, no further pruning is done, although pruning to a height of 6 m has been recommended to reduce fire risk. For the production of sawn timber, both dead and live branches up to a height of 7(−12) m ("high pruning") are removed to produce knot-free wood [5]. In a thinning trial, in Malawi, Missanjo et al. [16] studied the effect of first thinning and pruning on height, diameter at breast height, and volume growth in individual trees. The authors concluded about the importance of both practices in *P. patula* plantations, recommending their use to maximize the increase in volume production. The highest diameter and volume growth were registered when thinning and pruning were applied, while the highest growth in height was observed where there was pruning and no thinning.

Intensive silviculture aiming to maximize productivity and gains is traditionally carried out in commercial timber plantations within South Africa during the re-establishment phase, however, there is limited information as to the rotation end benefits of this input [10]. Thinning characteristics depend on initial spacing, site quality, and end product and affect tree growth through its effects on growing space. In Zimbabwe and South Africa, in forestry systems aimed at producing sawlogs, the ultimate goal is to have a stand of more than 400 treesha^{-1} of about 45 cm diameter, implying 25–35-year rotations. In Zimbabwe plantations with an initial 3 m × 3 m spacing (density of 1100 treesha^{-1}) may be thinned twice, with density reduction to 650 treesha^{-1} after 6–8 years, and to 400 treesha^{-1} after 12–15 years. In Madagascar, heavy thinning is recommended to reach a target density of 200–250 treesha^{-1} when the trees are 15 years old. For pulpwood schedules, rotations of 15–25 years are normal, resulting in trees with a bole diameter of about 30 cm [5].

The mechanization of harvesting has been transforming the practice of thinning, leading to increased use of row thinning to gain access to a stand with machinery while restricting the application of selective thinning in the areas between machine trails. Ackerman et al. [17] advert that this procedure carries the risk of irregular stand structure with resulting adverse effects on crown growth and its eccentricity and plasticity, potentially negatively affecting saw timber quality and volume production from the stands at final felling. These consequences, confirmed by the authors on a plantation of *P. patula* in South Africa, assume particular importance when the species is managed in long rotations, aiming for the production of sawlogs.

A brief characterization of silvicultural guidelines for the management of *P. patula* is depicted in **Table 1**. The prescriptions of the silvicultural activities that are carried out are in accordance to the references mentioned for plantations in Africa.

3.3 Models to support decision-making processes

To the best knowledge of the authors most of the biometric studies involving the development of tree and stand-level models for *P. patula* report to the species in Mexico (e.g. [6, 18]), but there are records on equations developed with data collected in other countries. In the GlobAllomeTree international web platform ([19], see also [20]), 14 out of the 38 allometric equations to estimate tree volume (v)

Year	Activity	Description	Observation
0	Site preparation		
0	Stand establishment: artificial regeneration (plantation)	Initial spacing about 2.4 m to 2.75 m, or wider (e.g. 3 m).	Closer spacing is recommended for saw log schedules. Wider spacing is recommended on poorer sites
1	Control of spontaneous vegetation	2–3 weeding operations to reduce the occurrence and growth of competitive vegetation	The vegetation management is performed either manually or chemically
4–6	Pruning	Trees are pruned to a height up to 2.5 m	The operation is recommended both for pulp and sawlog schedules. For the production of sawn timber, further pruning interventions are recommended at a later age to a height of 7 to 12 m. Whenever pruning coincides with thinning, it is carried out on the trees to be retained.
6–15	Thinning	One to two thinnings. Reduction of stems per hectare gradually or in a single heavy thinning, to a final density of 200 to 400 $treesha^{-1}$	Thinning applies for sawlog schedules but is not usual for pulp schedules. Frequently combines mechanical row thinning along with selective thinning within the strips with trees.
15–45	Final harvest	Final cut of the living trees.	Rotation of 15 to 25 years for pulp projects, rotation of 25–45 years for saw log schedules

Table 1.
Silvicultural guidelines for the management of pure P. patula *plantations.*

or biomass (b) of *P. patula* were developed with data collected in the African countries of Tanzania (6), South Africa (5), Kenya (2), and Rwanda (1). A summary of the available models with the specification of the explanatory variables and response variables is provided in **Table 2**, along with the reference studies ([19], references herein). The equations to estimate tree volume or tree biomass used as regressors one or a combination of the following variables, diameter at breast height (d), tree height (h), crown height (ch), tree basal area (g), and age (t). Listed in **Table 2** is a stand-level-type model allowing to estimate stand volume (V) using as input data age, stand basal area (G), and dominant height (h_{dom}).

Regarding growth models, data-driven models and process-based models are described for the species in East and South Africa [28–31]. Reference [32] presents and discusses progress made on predictive models for growth and wood quality for the species managed in South Africa for saw timber. Delgado-Matas and T Pukkala [33] elaborate on growth models for the species in Angola. Complementary information from a literature review of both growth models and tree volume equations for species in Africa can be found in this reference [33].

In the context of decision support models, two additional specific contributions should be highlighted, these are references [34] and [35]. The study by Gadow and Kotze [34], based on *P. patula* spacing experiments, refers to tree survival and maximum tree density. The authors estimated the self-thinning line (Reineke [36]) for the species and found it to be positively related to site index, with higher maximum density values in the better-quality sites. Mugasha et al. [37] provide a comprehensive study on the development of individual and stand models to support the decision on optimal rotation length for the species in Tanzania.

Allometric equation	Response variable	Explanatory variables	Geographical location	Reference
40551	Tree volume	d , h	Kenya	[21]
47709	Tree volume	d	Rwanda	[22]
41516, 41586	Tree biomass	d , ch	South Africa	[23]
45212, 46720	Tree biomass	d , h	South Africa	[23]
45871	Tree biomass	d	South Africa	[23]
38145	Tree volume	g	Tanzania	[24]
38656	Tree volume	d , h	Tanzania	[24]
39372	Tree volume	g , h , t	Tanzania	[25]
44165	Tree volume	d , h	Tanzania	[26]
46201	Stand volume	G , t , h_{dom}	Tanzania	[27]

Table 2.
Existing models for Pinus patula *developed for African forest systems (from [19]).*

3.4 Pests and diseases

Most of the insect pests harming *P. patula* are defoliators, particularly of the order Lepidoptera, the most noted being the families Arctiidae, Lasiocampidae, Noctuidae, and Saturniidae. The damage starts from the nursery stage by means of cutworms, several leaf rollers, and defoliators. The pests in plantations include adult leaf-eating beetles, adult bark beetles (mottled pine bark weevil) as well as sucking insects, such as pine wooly aphid. Diseases of the species comprise foliage leaf cast, tip die-back of the branches, and armillaria root rot [7]. *Sphaeropsis sapinea* was also mentioned as an economically important pathogen of *P. patula* in South Africa, causing rapid die-back and mortality of hail-damaged trees [37]. *Fusarium circinatum*, known as the pitch canker fungus (PCF), is one of the most important pathogens to natural and industrial pine forests, being a serious threat to *P. patula* [38]. Post-establishment mortality with *P. patula* in commercial plantations is currently the most pressing operational concern and poses a threat to the continued use of pure *P. patula* as a species [8]. *P. patula* has been identified as being particularly susceptible to the PCF [39]. Long-term control strategies include the usage of alternative species, hybridization, breeding, and selection programs to improve resistance [38]. Knowledge regarding the molecular basis of pine *Fustiaria circinatum* host-pathogen interactions could assist efforts to produce more resistant planting stock. Visser et al. [40] identified molecular responses underlying resistance against *F. circinatum*. According to the results found, delayed response and impaired phytohormone signaling contribute to pathogen susceptibility in *P. patula*.

In addition to insect pests and diseases, rodent-induced damage has also been reported in first-rotation pine plantations in South Africa 4–5 years after planting. Tree mortality was attributed to changes in the structure of shrub and grass assemblages within the plantation, causing rodents to feed on the pine trees [41].

3.5 Effects on biodiversity and relevance on aboveground carbon stock

The usage of *P. patula* in a plantation system does not appear to negatively impact biodiversity. In fact, in a study conducted by [42] in western Kenya, the authors reported there was no significant variation in woody species richness among disturbed primary forest, old-growth secondary forest, middle-aged

secondary forest, mixed indigenous plantation, and *P. patula* monoculture plantations. Old-growth and middle-aged secondary forests had relatively higher woody species diversity indices than *P. patula* monoculture plantations, but the difference was not statistically significant. Regarding the contribution to aboveground carbon offset, results indicated that *P. patula*, had a lower carbon stock than other types of forests. This was explained by the smaller stem diameter and wood specific gravity lower than or comparable to the other species and forest types in the study, being predominantly associated with the schedules adopted for the plantations of *P. patula* of short (pulpwood) to medium rotation length. A short rotation length affects biomass accumulation (which will be comparably lower) and wood density (also lower, as noted in Section 3.1).

4. Interest of *P. patula* within the framework of the sustainable development goal (SDG) 15

Major change processes in forests around the globe are deforestation, afforestation, and reforestation (**Figure 3**). Deforestation and Afforestation represent the transfers between forest and other land use classes. Reforestation occurs when forests regrow after temporarily having had below 10% canopy cover, but were considered forests throughout that time [43]. Reforestation envisages the recovery of forest areas and can be achieved with the plantation of forest species. Forest plantation is expanding in African countries. The great majority of planted trees are exotic species chosen for their capability to grow rapidly to produce wood of desired quality. *Eucalyptus* is the most widely planted genus covering 22.4% of all planted area, followed by *Pinus* (20.5%).

Well-managed forest plantations can help to alleviate pressure on natural forest resources. Further, as depicted in **Figure 3**, both processes of afforestation and reforestation act in the opposite direction of degradation of (forest) land. Two SDG targets of SDG 15 are explicitly identified [2]—ensuring the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems and their services, particularly forests (15.1); promoting the implementation of sustainable management of all types of forests, halting deforestation, restoring degraded forests, and increasing afforestation and reforestation globally (15.2).

The use of forest species, such as *P. patula*, considered in this review, in forestation or afforestation programs in Africa can be beneficial in counteracting or minimizing the pattern of forest area loss reported in [1]. To achieve better results, further research should be carried out on the species. The review summarized in the previous sections shows that there are gaps in knowledge for the species outside its natural range. Specific issues to prioritize in research embrace optimal silvicultural guidelines and mortality at young stages of development under an adaptive forest management perspective. Intensive silviculture is carried out within commercial



Figure 3.
Major forest changes processes with a reference to SDG 15. Based on [43].

timber plantations within South Africa during the re-establishment phase, however, there is limited information as to the rotation end benefits of this input. Post-establishment mortality with *P. patula* in commercial plantations is currently the most pressing operational concern and poses a threat to the continued use of pure *P. patula*. Research on these topics is, therefore, encouraged.

5. Conclusions

P. patula is a very fast-growing tree and the most widely planted pines species within African commercial plantations. The species is planted in Ethiopia, Kenya, Tanzania, Malawi, Zimbabwe, Madagascar, and South Africa and is mainly used for timber and firewood. The increase in forest area and its maintenance in good conditions contribute to the Sustainable Development Goals of UN Agenda 2030. Besides the positive impacts explicitly associated with SDG 15, positive effects of the forest sector might be expected in SDG 1 (income to fight poverty), SDG 6 (freshwater), and SDG 13 (carbon capture). Achievement of any of the goals requires appropriate knowledge of the forest species traits and their adequate forest management. The review on the species here presented aims to help accomplish these purposes, by providing information on the species and identifying research priorities.

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Conflict of interest

The authors declare no conflict of interest.

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