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Impacts of Invasive Species on Commercial Forest Plantations in Africa- A Review

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Abstract

Planting forests with non-native or exotic species are increasing worldwide as the demand for forest product, ecosystems and environmental benefits continue to grow. Characteristic life-history traits such as simple establishment, speedy growth, high propagule pressure, and low shade tolerance render the exotic trees better alternatives in commercial forest establishment. Several exotic tree species in forests now feature notably on the lists of invasive alien plants in many parts of the world and require to be sustainably managed to provide opportunities that enhance economic development. However, the consequence of exotic invasive species in commercial forestry remains largely fragmented in development and management. This paper, therefore, attempts to collate this information by looking at the status of exotic invasive species in commercial forests, their beneficial aspects and threats in commercial forestry. Management of exotic invasive species through a review of 126 papers from secondary sources discussing invasive species and their consequences on commercial forests are also explored. The overall impact is huge economic and ecological loss. The knowledge is useful to predict problems in other regions of the world with the same species and to guide research or management actions on other problematic but less studied tree species.

Keywords: Commercial forestry, invasive species, exotic species, forest management

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Introduction

Protecting forests from fire, insects, and diseases is part of sustainable forest management (Siry *et al.,* 2018; Wenhua, 2004; Keenan & Nitschke, 2016; Dai *et al.,* 2011). Kumar & Prasad, (2014); Kannan *et al.* (2013) stated that invasive species are a growing threat to the world's forests. Forests greatly play a key role, in regional, and local economies through the provision of various products and ecosystem services that support human livelihoods and biodiversity (Karki and Chowdhary, 2019; Sheppard *et al.*, 2020; Bhandari et al., 2016; Tadesse et al., 2014). Due to the persistent demand for forest resources, the natural forest has continued to diminish (Ke *et al.*, 2019; Ogundele *et al.,* 2016; Sloan & Sayer, 2015).

Subsequently, afforestation programmes are high on the forestry priority agenda in several countries to increase the contribution of the tree species to human needs (Deng and Shangguan, 2017; Subandi *et al.*, 2019; Pistorius *et al.,* 2017). Numerous tree species have been planted for many purposes, such as the provision of energy, building materials, sources of food, soil conservation, ornamentation, and various forms of agroforestry practices (Himes and Puettmann, 2020; Nduwamungu, & Munyanziza, 2012). Concerning commercial forestry, there are a relatively low number of tree species in several regions of the world that are currently being planted (Booth, 2017; Marron and Epron, 2019).

This is because commercial forestry focuses more on the value derived from the tree (Flanagan *et al.*, 2019). On the account of high commercial value account alone, several recommendations have led to the cultivation of non-native or exotic trees within the forests.

A plant species is considered non-native or exotic/alien if it grows in an ecosystem where it did not originate (Castro-Díez *et al.*, 2019; Rai & Singh, 2020). In most cases, exotic species have not been thoroughly tested or grown commercially (Ennos *et al.*, 2019). The proliferation of exotic species as commercial forest and plantation establishment is based on exotic species over the past years for several purposes including (1) Maintaining and/or increasing forest productivity (2) Increasing resilience of forests and (3) Retaining biodiversity associated with threatened native species (Benra *et al.*, 2019; Song *et al.*, 2019). Preference for these exotic species stems from several attributes such as (1) ready availability of information on propagation techniques, (2) life-history traits such as simple establishment, silvicultural properties and management practices, and (3) fast growth rates, and (4) production of wood that can be used for various purposes in a relatively short period (Mazía *et al.*, 2019) as well as low shade tolerance (Dash *et al.*, 2019; Sweeney *et al.*, 2019), yet these tree species have tendencies to become invasive in areas where they are introduced.

Invasive plant species are non-native plants that are introduced outside their home range and produce offspring in large numbers and at considerable distances from parent plants that eventually affect the native plants (Shackleton and Shackleton, 2016; Moos *et al.*, 2019). In some cases, invasive species refer to plants that have been introduced from other regions and spread like wildfire to be completely dominant in their new habitat (Moos *et al.*, 2019). An increasing number of reports continue to document a high number of forest plantations with introduced exotic tree species that tend to become invasive (Fan *et al.*, 2019; Tietze *et al.*, 2019).

There are beneficial invasive tree species in commercial forestry (Ismail *et al.*, 2016; Xavier *et al.*, 2019) as there are threats of the same in several regions of the world (Xu *et al.*, 2012; Crosti *et al.*, 2016; Early *et al.*, 2016), However, the threat and beneficial effects of invasive species may rely on the management initiatives in place for the invasive exotic trees (Dodet and Collet, 2012). There is however a dearth of information on the performance of exotic invasive species in commercial forestry. Therefore, this review aims to highlight and conglomerate studies on the invasive exotic species at the global, regional and local scale, and discuss their significance and threats.

This review paper focuses on exotic (i.e., alien) invasive trees that are introduced into commercial forest plantations. Plantations corresponding to different production objectives (biomass, paper, or timber) are considered without limitations in terms of geography or forest types. We begin by analyzing the global trends, then traditional and specialized types of plantations and introduced tree species, and plantations on disturbed land. The paper looks at the trends in African countries extending the focus to Kenya. Based on these considerations, we finally discuss the significance and threats of invasive species on commercial forest plantations.

Methodology

This study assembled the secondary evidence from the literature on the ecological impacts of alien plants on commercial forest plantations. The scientific papers analyzed were obtained from different sources such as Google Scholar, Science-Direct, PubMed, SciFinder, and Scopus. Systematically used keywords include invasive alien plants, global, Africa, Kenya, and commercial forests in journal articles. Data was collected by logging onto each journal's dedicated website and downloading all of the articles. The titles, summaries, and keywords of the linked publications were then assessed carefully, and the papers about invasive plant species were then discussed in depth. The study used 126 articles which addressed the significance and threats of invasive species on commercial forest plantations.

Results and discussion

Global status and trends of exotic invasive species forests

The global demand for wood has led to the plantation of fast-growing, adaptable species (Vor *et al.,* 2016). In some regions, exotic species are best for high production when native species fail. Most invasive forest species are introduced voluntarily, usually in commercial plantations (Akin-Fajiye and Gurevitch, 2020). Invasive species are productive due to their easy establishment and fast development, especially on harsh sites where native trees don't thrive (Redwood et al., 2019). In natural and semi-natural habitats, trees have the most invasive plant species (Dalmolin *et al.,* 2018).

The invasive alien species records extracted from the combined Global Invasive

Species Database (GISD) spanned 243 countries and overseas territories, with 1517 different species represented (Fig. 1). In terms of plant species, the results indicated 886 terrestrial plants and 52 aquatic plants. Fig 1(a) shows the number of invasive alien species per country (S_{Inv}) based on the GISD databases. Results (excluding overseas territories) ranged from $1 \leq S_{Inv} \leq 523$ invasive alien species per country while results for the included overseas territories were $1 \leq S_{Inv} \leq 1071$ invasive alien species per country. Over 85 countries have $S_{Inv} \leq 15$, with 42% of these countries being located in Africa and West Asia.

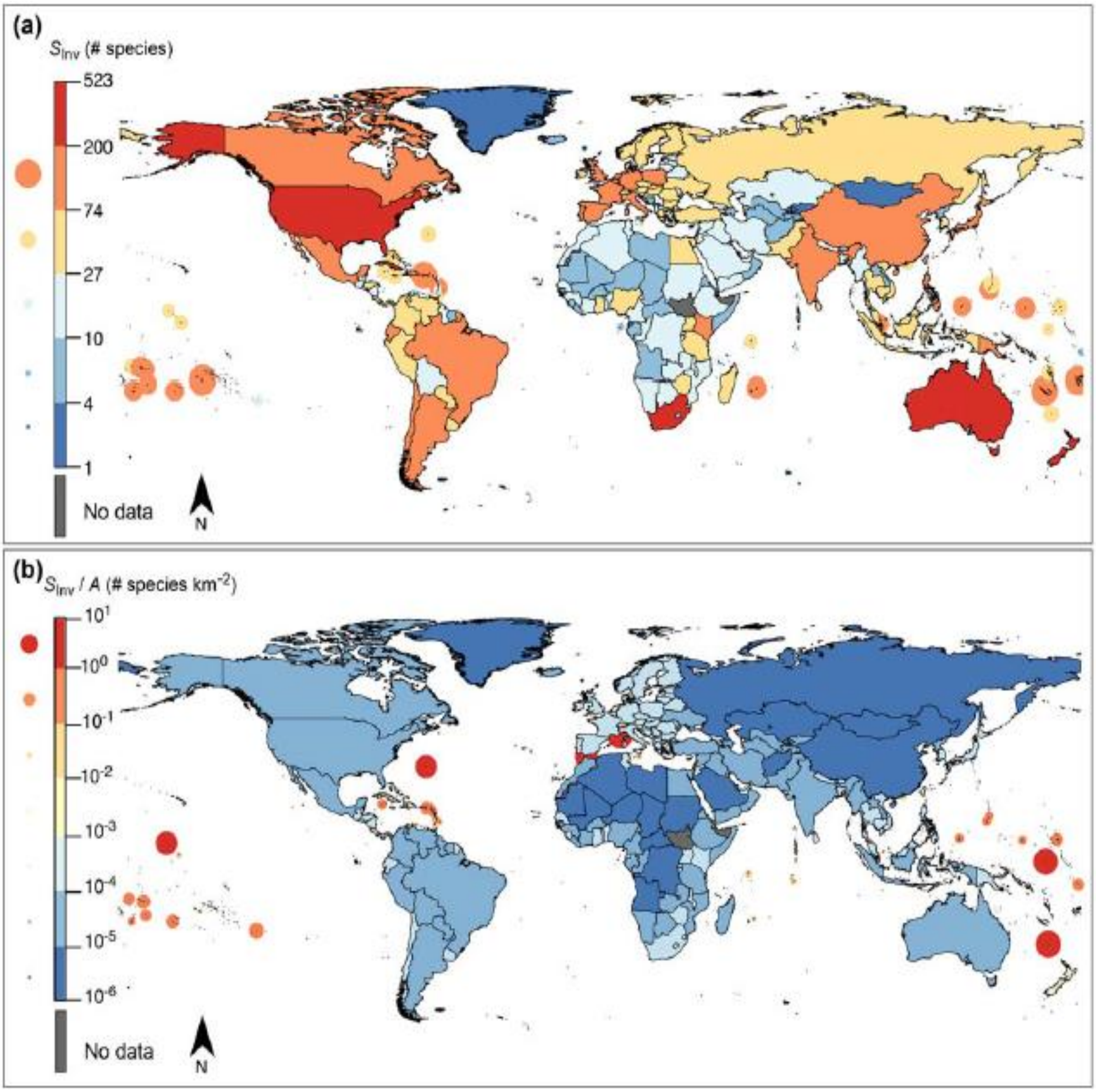

Figure 1: Global map of the number of invasive alien species per country, excluding overseas territories based on the Global Invasive Species Database (GISD, 2016)

In Fig. 1(b), the number of invasive alien species per country was normalized by the country's land area A (km^2). Fig. 1(a, b) shows that the economically developed Global North along with some newly industrialized countries (e.g. South Africa, China, India, Brazil) have generally received the most invasive alien species, but also small tropical and sub-tropical islands, in particular, have high numbers of invasive alien species per km^2. The circles in Fig. 1(a, b) illustrate the number of invasive alien species in countries with a land area A < 20,000 km^2. As emphasized in Fig. 1(b), 61 (80%) of the 76 small islands with recorded invasive alien species and A < 20,000 km^2, had > 0.01 species per km^2.

The 10 countries with the highest number of recorded invasive alien species are listed in Table 1. The country with the greatest number of recorded invasive alien species excluding overseas territories is the USA (S_{Inv} = 523) followed by New Zealand (S_{Inv} = 329); including overseas territories in the USA (S_{Inv} ≥ 1071) followed by France (S_{Inv} = 5927). Based on the GISD (2016), the overall, invasive alien species type (number of countries where recorded) was: terrestrial plants (236 countries) and aquatic plants (110).

Table 1. The countries with the highest number of recorded invasive alien species include overseas territories. Also shown is the number of invasive alien species per 100,000 km².

Country (excluding overseas territories)	S_{Inv} (species)	(S_{Inv}/A) (× 10^5) (species per 100,000 km²)	Country (including overseas territories)	S_{Inv} (species)
1. USA	523	5.7	1. USA	1071
2. New Zealand	329	124.9	2. France	927
3. Australia	322	4.2	3. New Zealand	511
4. Cuba	318	298.8	4. Australia	465
5. South Africa	208	17.1	5. UK	463
6. French Polynesia	190	5191.3	6. Cuba	318
7. New Caledonia	183	1001.1	7. China	220
8. Reunion	173	6889.7	8. South Africa	208
9. Fiji	167	914.1	9. Fiji	167
10. Canada	166	1.8	10. Canada	166

Source: GISD (2016)

Many countries have several species native to that country that has become invasive elsewhere; this is represented using the variable S_{Nat} and plot them globally in Fig. 2. Just fewer than 55% of the 243 countries (excluding overseas territories) have 'exported' 56 or more recorded species (i.e. S_{Nat} ≥ 56); 16% have S_{Nat} ≥ 126. The five countries that contribute the most invasive alien species to other countries are China (S_{Nat} = 257), India (S_{Nat} = 230), Mexico (S_{Nat} = 218), Turkey (S_{Nat} = 5193) and France (S_{Nat} = 186) with the Asia Pacific region being the biggest 'exporter' of invasive alien species, with 603 species native to that region being invasive elsewhere. Nearly 55% (32 out of 58) of countries in the African region have a low number of recorded species that have become invasive elsewhere (S_{Nat} <56).

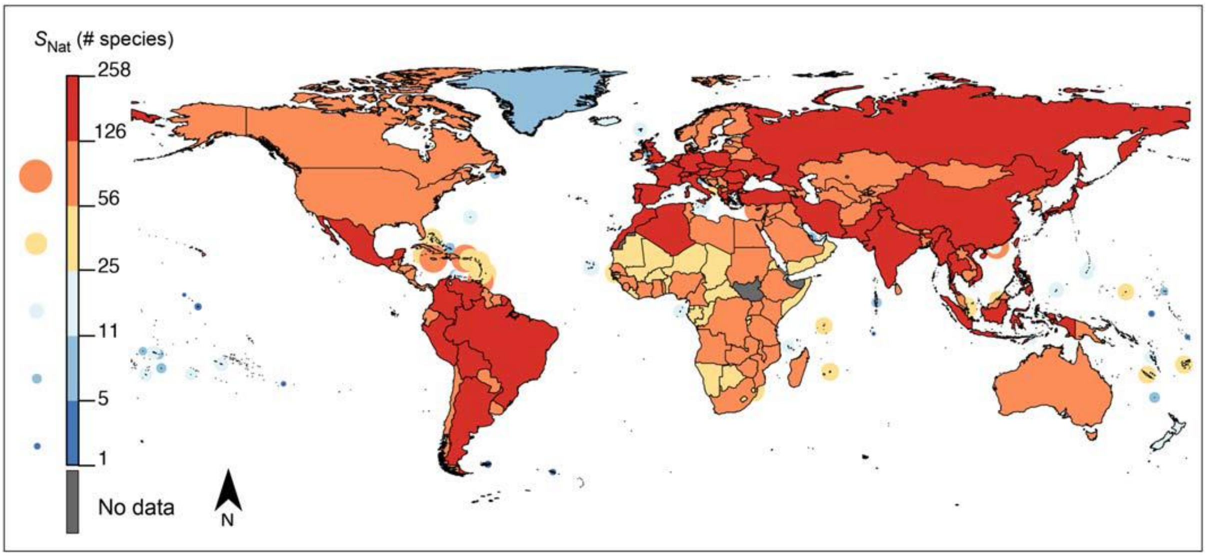

Figure 2: Global map of S_{Nat}, the number of species native to a country but considered invasive alien species in other countries, as based on the Global Invasive Species Database (GISD, 2016)

In 2018, the total area of planted forest was estimated to be 264 million ha (about 7% of the total global forest area (Chiarucci and Piovesan, 2020). Planted forests by definition comprise trees established through planting and/or through deliberate seeding of native or alien tree species, including the use of clonally propagated materials and genetically modified trees. The land is either afforested or reforested. East Asia, Europe, and North America have the most planted forests, accounting for 75% of the global planted forest area. South America, Southern and Southeast Asia follow (Nepal et al., 2019).

Some parts of Europe, especially the south, lack highly productive native tree species suited to plantation forestry, so foresters rely on non-native species (Rigling *et al.,* 2016). About 9.5 million hectares (4.4% of the forest) are dominated by introduced tree species (excluding the Russian Federation, Forest Europe, 2015). In the Russian Federation, less than 100,000 ha of its vast forest area was reported as comprising non-native trees (66,000 ha in 2015) (Brus *et al.*, 2019). In Denmark, Iceland and Italy introduced tree species are reported to occur also on other wooded lands (Pyšek, 2016; Thurm *et al.*, 2018).

It has been estimated that among 443 forest species that may be considered invasive, 292 are used in forest plantations. Most of these species belong to the Leguminosae, Pinaceae, Myrtaceae, Rosaceae and Salicaceae families (Crosti *et al.*, 2016). Two genera stand out as particularly important: *Acacia* which has about 22-25 species recognized as invasive as well as genus *Pinus* which has 22 species classified as invasive (Dodet and Collet, 2012; Rejmánek and Richardson, 2013). Commercial Pinaceae species have a higher risk of invading neighbouring ecosystems than ornamental species (Nuez *et al.,* 2017).

Trends of exotic plants species in African forests

Acacia species, *Pseudotsuga menziesii*, *Picea sitchensis*, *Salix*, *Pinus spp., Larix spp.,* Populus hybrids and clones, *Robinia pseudoacacia, Quercus rubra*, and some Eucalyptus species are important traditional alien tree species (Beech *et al.,* 2017). Aside from "traditional" plantations, which are the most important and widely distributed, alien trees have been used in "specialised" plantations for gardening, protective functions, arboreta, erosion preservation, and expanding forest area through afforestation of neglected or derelict land (Campagnaro *et al.,* 2018; Vtková et al., 2020). Prunus species, including Prunus africana, are ranked third in invasiveness (Cunningham *et al.,* 2016).

Africa's invasive species are poorly studied. Tropical Africa is only mentioned at 6% in the Invasive Woody Plant Database. *Acacia mearnsii* is one of Africa's most invasive alien tree species and one of the world's worst invaders (Le Roux et al., 2011; Boudiaf *et al.,* 2013). In South Africa *A. mearnsii* was originally planted on 107,000 ha but is estimated now to have spread to a total area of 2,500,000 ha (Gaertner *et al.*, 2016). This species native to Australia has been shown to compete with native species, and reduce biodiversity and water availability in riparian zones (Le Roux *et al.*, 2011). Other species considered invasive were *Psidium guajava* (Guava tree), *Prosopis juliflora* (Mesquite), and *Opuntia ficus indica* (Prickly pear cactus) (Makoni, 2020).

Witt *et al.* (2018) reported that in East Africa covering (Ethiopia, Kenya, Tanzania, Uganda and Rwanda), 110 genera and 47 families have 164 invasive alien species. Fabaceae has 27 species, Asteraceae 17, Solanaceae 13, and Cactaceae 8 (Witt et al., 2018). *Senna* (Fabaceae) has the most species (8), followed by *Acacia* (5), *Opuntia* (5), and *Ipomoea* (4) (Convolvulaceae). Most invasive alien species in Kenya are from the American tropics, with a few from Asia, including *Azadirachta indica* (Meliaceae), *Broussonetia papyrifera* (Moraceae), and *Rubus niveus* (Rosaceae). Most of these invasive alien species (128; 80%) were introduced between 1881 and 1960*. Chromolaena odorata* (Asteraceae), an aggressively invasive shrub, was introduced in 2009.

Obiri (2014) identified several invasive plant species in the Kakamega and Mt Elgon Forest Ecosystems in Kenya and Uganda, with three (*Solanum mauritianum, Psidium guajava, and Lantana camara*) being common and deleterious to both ecosystems. Acacia melanoxylon is invasive in Mt. Elgon Forest, and *Juniperus procera* is non-native in Kakamega. The study suggested mitigation measures to be put in place to limit invasive species and maintain forest diversity, ecological integrity, and functioning.

Makhambera (2014) assessed the environmental impact of woody plant invasive species in Malawi's Mulanje Mountain Forest Reserve, where they are considered the second largest threat to biodiversity after direct habitat destruction. The spatial distribution of woody species varied across the three transects. Two exotic and invasive woody species were among the 27 observed. *Hypericum revolutum, Kotschya Africana, Protea nyasae, Pinus patula, and Heteomorpha trifoliate* were the most abundant species, with *Pinus patula* being the invasive species. *Rubus ellipticus* was another woody invasive species identified during the transect walk; both were dominant on the western transect.

Beale *et al.* (2020) surveyed invasive and potentially invasive alien plant species in Kenya's biodiversity hotspot Laikipia County and reported that145 alien plant species were recorded, 67 and 37 (including four species of uncertain origin) were naturalised or invasive, and 41 species were naturalised or invasive outside of Laikipia. Most (141) of these species were introduced as ornamentals or had other uses; most (77) originated in tropical America. *Opuntia stricta, O. ficus-indica, Austrocylindropuntia subulata* and other succulents were widespread.

According to Noba et al. (2017), West Africa (Gambia, Ghana, Ivory Coast, Senegal, Burkina Faso, and Sierra Leone) is the habitat of 113 invasive species belonging to 94 genera and 43 families. Poaceae (17 species) and Leguminosae were exceptionally well-represented (16 species). Cyperaceae (9 species) and Asteraceae (13 species) (6 species). In Euphorbiaceae, Solanaceae, and Nympheaceae, there are four species. The most prevalent invasive species in West Africa are found in eight different nations. The species *Chromolaena odorata, Eichhornia crassipes, Salvinia molesta, Typha domingensis,* and *Pistia stratiotes*. Depending on the availability of data, the prevalence and significance of invasive plants vary by country.

Impacts of invasive species in plantations in commercial forestry

Planting exotic or alien invasive species creates forest-like conditions (Paz-Kagan et al., 2019). Numerous studies in tropical or temperate regions show that invasive species strongly influence the composition of native plant communities in a negative way (de Groot et al., 2020; Huebner, 2020). Numerous problematic species were introduced by governments and aid agencies to boost natural resources, but their impacts far outweigh any benefits. There is a link between invasive plants, ecological integrity and human social livelihoods (Reynolds *et al.*, 2020). Invasive species are known to impact negatively on the conservation of biodiversity as well as the livelihoods of rural people that depend heavily on natural resources (Obiri, 2011). Invasions by alien plants have added a new dynamic to forest and landscape management, and they often lead to conflict over resources (Reynolds *et al.*, 2020). Reduced rangeland capacity to support livestock, combined with growing human populations and competing for land uses, has marginalised many rural pastoralists. Identifying and quantifying introduction impact is difficult. Even when acknowledged, it may be difficult to classify impacts as neutral, positive, or negative because of the observer's cultural background. Depending on your perspective, most introduced tree species have positive or negative effects (Soliman et al., 2012). All impacts, economic, ecological, or social, rely on the species' maximum concentration and site perseverance (Sanderson et al., 2012).

Indirect economic implications linked to the introduction or control costs have been reported (Aukema *et al.,* 2011). Many authors have assessed the economic consequences of invasive species in a general way, but few have focused on invasive exotic natural forests introduced through plantations. Exotic forest pests (arthropods, pathogens, etc.) cost the U.S. $6 billion per year (direct losses, control operations) (Shackleton *et al.,* 2019). Total invasion costs include absolute control campaign costs and indirect ecosystem impacts. However, Holmes et al. (2009) reported that the greatest economic impacts from invasive forest species are due to the loss of non-market services (water filtration, wildlife habitat, carbon sequestration, landscape esthetics, etc.), services that are not taken into account in many economic studies.

Invasion by forest plantation species of natural or semi-natural open habitats results in a substantial change of the initial habitats, progressively commuting into forest habitats. Existing plant communities that were specific to open habitats are deeply transformed, which may result in a global loss of plant, animal or habitat diversity (Weidlich *et al.*, 2020). Numerous invasive tree species have a powerful impact on global resource availability, soil, and microclimate, as evidenced by a long list of examples from around the world. Invading tree species have reduced soil water reserves and increased fire frequency in South Africa. Due to their ability to fix nitrogen, Australian Acacia species like *A. cyclops* and *A. saligna* have changed the nutrient cycle in some ecosystems.

Invasive plant species threaten East African drylands' environment and economy (Obiri, (2011). They have degraded the environment and harmed human well-being by reducing the availability of goods and services, spreading diseases, and reducing economic opportunities. Loss of livelihood and food security have resulted (Keller, et al., 2018; Shackleton et al., 2019; Sudmeier-Rieux & Ash, 2009). Mesquite tree devastation has led to constitutional court cases between local communities and the Kenyan government. In Kenya, NEMA and MENR monitor and control invasive species, but their results have been poor. As communities move into drylands and are unprepared for the hazards, invasive plant-related disasters rise (Obiri, 2011). Therefore, environmental policies, practices and guidelines need to be an integral part of managing the exotic invasive species. This includes, first, incorporating wise land-use planning whereby irregular disturbances such as random fires and the traditional dry season woodland burning that destroys existing vegetation are reduced. Secondly, since most invasive plants are introduced from foreign regions, it is critical to identify, assess and monitor the risks of plant species being introduced. Introductions should be preceded by checking for any disaster effects a plant may have caused in a similar environment. Third, establishing early warning systems and other preparedness measures, such as ensuring that dry forest floors do not accumulate fuelwood, which increases fire intensity and opens habitats for invasive plants. Fourth, it's important to strengthen environmental management institutions, mechanisms, and capacities (especially at the community level) to build invasive species resilience. The National Environmental Management Authority must increase its efforts to educate local communities about invasive species.

Management of exotic invasive tree species in commercial forestry: present practices and research requirements

Non-native trees planted for production or other purposes can become invasive in many countries or regions (Muzika, 2017; Martnez-Jauregui *et al.,* 2018). Despite increased awareness of invasive species, appropriate tools to assess and manage risks associated with exotic tree species in plantation forestry are not available or preclude some management actions. Decades ago, pioneering work began on invasive plantation trees (Albers et al., 2018). Many ambitious programs to control major invasive plantation tree species (*Pinus Prosopis* and *Acacia* species) have been implemented and thoroughly analyzed, providing helpful insights into what may be expected from the control of invasive forest trees (Braun *et al.*, 2016). The main lessons learned are that the management of exotic plantation trees must be thought out at the landscape level and must combine a variety of actions targeted at different stages of the invasion process (Hess *et al.*, 2019). Two types of complementary strategies are classically distinguished: prevention and early detection, and control of the invasion in progress (Weidlich *et al.*, 2020). Existing and future alien tree plantations must be managed to maximise current benefits while minimising risks and negative impacts without compromising future benefits and land uses.

The long initial lag phase and slow dynamics observed in many forest plantation tree species may offer opportunities to control the species while populations are small. The lag and early spread phases have few individuals, making them difficult to detect and quantify.

Conclusion and recommendation

Forest plantations, whether for commercial or restoration purposes, are a very efficient pathway for plant invasion or have resulted in widespread invasion by exotic plantation trees. Due to rising global demand for wood, pulp, and bioenergy, many regions are planting more exotic tree species. This trend will increase large-scale invasion issues and spread the problem to regions without a major tree invasion. Exotic plantation trees such as Pinus and Acacia have many available case studies. This study contributes to a fair understanding of invasion dynamics of the main tree characteristics that may favour invasion, management and the main habitats currently invaded. *Pinus* and *Acacia* are presently used as model species and are the focus of a large share of the research effort on invasive plantation trees. Rapid progress on these widely-used species must be made to enhance current management practices. Most of the studies on these model species were conducted in South Africa, New Zealand and Australia, three countries with a long history of afforestation and invasion. Knowledge gained in these countries is useful to predict problems in other regions

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