Status of *Opuntia* invasions in the arid and semi-arid lands of Kenya

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Abstract

Invasive alien species (IAS) are among the leading threats to biodiversity, food security and human well-being. *Opuntia* (prickly pear cactus) is one of the most widespread and naturalized in the arid and semi-arid areas of Kenya, with extreme effects on rural livelihoods and the environment. However, comprehensive information on the status of invasion in the country is lacking, which is crucial for developing strategies for prevention and management. This paper, therefore, provides an overview of the interacting factors that influence its invasion in Kenya in terms of species diversity, pathways of introduction, negative impacts and the effectiveness of regulations and control measures. Seven invasive species of *Opuntia* are present in the country with the most abundant (*O. stricta*) being under biocontrol trial. These species have the same habitat preferences, physiological traits, negative impacts, introduction pathways and management options. Invasion is mainly attributed to changes in land use and consequent land degradation. Introduction pathways are largely intentional for ornamental purposes but unintentional at a local scale through escape from gardens and natural dispersal. The most applied methods of managing *Opuntia* are mechanical and chemical methods that are unsustainable and labour-intensive at large scale. Effective policies are therefore needed to prevent an increase in the significant negative impacts caused by IAS including those that have a limited distribution.

Keywords: Biological invasions, invasive alien species, *Opuntia*

Review Methodology: The approach employed was a review of published information from a variety of sources, including online scientific publications, books, field guides and experts' opinion on invasive alien species with a focus on *Opuntia* species in Kenya. Information was also gathered from relevant databases, including the Global Invasive Species Database, National Museums of Kenya, Centre for Agricultural Biosciences International (CABI), BioNET-EAFRINET, Germplasm Resources Information Network (GRIN), Flora of North America, Kenya Wildlife Service, Kenya Forestry Service and the Ministry of Environment and Natural Resources. Key priority pathways and impacts were categorized according to ecological and socio-economic impacts as follows: Minimal Concern (MC) – discernible impacts but no effects on individual fitness of native species; Minor (MN) fitness of individuals reduced but no impact on populations; Moderate (MO) – changes to populations but not to community composition; Major (MR) – community changes that are reversible; and Massive (MV) irreversible community changes and extinctions. They were also categorized based on the current framework of invasive species.

Introduction

Invasive alien species (IAS) are those species whose introduction threatens ecosystems, habitats or species. They are regarded as among the biggest threats to global ecosystems and biodiversity [1]. They have a high ecological and competitive ability as well as efficient reproduction and dispersal mechanisms. In a new environment, such species prosper in absence of predators or parasites that would regulate their relative abundance [2]. Besides, IAS are able to occupy vacant niches or take advantage of ecologically stressed or disturbed environments by changing resource availability [3]. This, in turn, increases the competitive ability of the IAS in the new environment. In the rangelands, impacts of IAS are mostly related to livestock production and include livestock deaths, reduced forage, interference with grazing practices, increased costs of management and reduced livestock yields [4].

They may also negatively impact wildlife habitats, deplete soil and water resources and reduce the diversity of plants and animals. Effects on rural livelihoods are linked to the extra cost of management, reduced ecosystem productivity, increased the threat to health and reduced utilities from natural resources [5]. These impacts not only reduce biodiversity but also threaten food security and human well-being.

Much review on the status and impacts of IAS around the world has been done to update knowledge on the occurrence and drivers of introduction [6–8]. Such studies are crucial for developing protocols for prevention and management. Nevertheless, more comparative studies on the target species, their pathways of introduction and spatial distribution are necessary to improve understanding of the interacting factors that influence their invasion. Pathways of introduction can either be intentionally for some benefits (e.g. use in biological production systems, landscaping and ornamental purposes) or unintentionally through transport, trade and travel [9, 10]. Identifying these pathways provide information to reduce the rates of unintentional introductions and for developing interventions for monitoring and management [9]. This not only informs the development policies and management strategies but also evaluates the effectiveness of control measures.

The cactus family (Cactaceae) is among the most widely introduced IAS across the world due to its popularity in the horticultural trade [6]. *Opuntia* Mill (Prickly pear cactus) which is native to America is the most common and naturalized in the arid and semi-arid lands of Kenya. The genus is also naturalized in many parts of the world, including Australia, Europe and many African countries [6]. In Kenya, *Opuntia* species were introduced in the 1940s as ornamental plants in the Northern drylands but their distribution is basically being changed by human activities. [11]. Some studies have proposed that *Opuntia* invasion after 50 years of introduction is as a response to changes in land use primarily settlement of pastoralists, followed by overgrazing and subsequent land degradation [11]. Despite the urgency in controlling the species, there are various gaps that hinder its management in East Africa. These include a poor description of the species because of variation in growth form, lack of information on proper management and poor monitoring and control measures [12, 13]. A broad national assessment of particular taxa of concern is, therefore, necessary for the formulation of appropriate control strategies. This may uncover new patterns, processes and risks that can improve the existing management strategies [6].

Description of Opuntia

Opuntia belongs to a group of plants known as a cactus (plural: cacti'). It is the largest genus in Family Cactaceae with more than 360 species and a range of geographical distribution. Cactus plants are of different shapes, sizes and growth forms and often with clusters of spines that arise from modified axillary buds called areoles [6]. The stems (pads) are also of varied lengths and widths and generally flattened [14]. This morphological variation is a trait that is strongly associated with invasiveness [15]. About 1600 species of *Opuntia* are recognized worldwide. Most have become invasive due to their ability to survive well in dry periods, compete well in disturbed conditions, have low levels of parasites and have a high reproductive potential [16]. However, description of cactus plants is generally difficult because of variation in phenotypes and presence of many hybrids [17].

Opuntia species form dense thickets through vegetative reproduction when detached cladodes become rooted in the ground [18]. They also have a specialized photosynthetic system known as Crussulacean Acid Metabolism with the ability to withstand prolonged drought and high temperatures [19]. The flowers range in colour depending on the species and bloom once a year [20]. Flowers open on a single day or 2 days consecutively hence well suited to reducing the risk of poor or no pollination [21]. The flowers are pollinated effectively by bees and beetles [22]. The fruits are red to reddish-purple and vary from pear-shaped to almost spherical. The species produce many seeds that are spread by various agents, including baboons, birds and large mammals [18, 23]. Germination occurs during the rainy season, although seeds can persist in the soil for at least 19 months [21]. Plants reach reproductive maturity at about nine years of age and can live longer than 30 years [21]. In addition, *Opuntia* species have relatively shallow and horizontally spreading roots that use water efficiently [24]. Such traits ease their spreading and colonization in dry areas.

Species types and distribution

Seven species of *Opuntia* are present in Kenya and have similar traits and habitat preferences (Table 1). These species are weeds in many parts of the world [25] and in most cases, they occur in association with each other [26]. The counties most invaded include Narok, Laikipia, Baringo, Nakuru and Taita Taveta (Figure 1) with small patches occurring in the neighbouring counties. *Opuntia stricta* var. *stricta* is one of the most widespread in Kenya [27]. The species was introduced in Central Kenya as an ornamental plant and has since spread across the rangelands and conservation areas [11]. It is widespread and abundant in Laikipia County and Taita Taveta [27]. In Ethiopia, the variety is widespread and abundant in the Eastern part where it is associated with *O. ficus-indica* [27]. Further studies show that the species grow in association with *Opuntia elatior* along the Kenyan coastline with a few infestations near Lake Baringo [27]. However, it has little benefits and is the most problematic in terms of impeding mobility, reducing fodder availability and impacting

Table 1 *Opuntia* species present in Kenya with their common names and the distinguishing features.

	Species	Common name	Description	Habitat
1.	*Opuntia elatior* Mill.	Red flower prickly pear	Forms dense branched clumps, cladodes are olive-green and egg-shaped with almost parallel sides, spines are needle-like and dark brown	Disturbed and open lands, roadsides, grasslands and dry gullies in arid and semi-arid areas
2.	*Opuntia engelmannii* Salm-Dyck	Cows tongue cactus	Erect shrub with many ascending to sprawling branches forming dense clumps, cladodes are broadly egg-shaped to diamond-shaped or tapering at the end, spines are white to yellow, red to dark brown at the base	Disturbed and open lands, sandy and gravelly soils and grasslands in arid and semi-arid areas
3.	*Opuntia exaltata* A. Berger	Long spine cactus	Much branched shrub and develops a trunk with age, curved and cylindrical cladodes with small rounded outgrowths, spines are straight and yellow-brown	Disturbed and open lands, grasslands and roadsides
4.	*Opuntia ficus-indica* (L.) Mill.	Sweet prickly pear	Shrub forming a trunk with age, cladodes are much longer than broad, spines are white, absent or 1–2 or more per areole	Most common in arid and semi arid areas, conservation areas, disturbed and open lands, savannah and roadsides.
5.	*Opuntia microdasys* (Lehm.) Pfeiff.	Teddy-bear cactus/Bunny ears	Forms thickets, cladodes are velvety, egg-shaped or almost round, no spines but many glochidea	Disturbed and open lands in arid and semi-arid areas
6.	*Opuntia monacantha* Haw.	Drooping prickly pear	Shrub with a large, much-branched top and drooping upper segments, cladodes are egg-shaped to somehow elongated and tapered towards the base, many spines on the trunks	Disturbed and open lands, roadsides, abandoned agricultural lands, savannah and coastal bush lands
7.	*Opuntia stricta* (Haw.) Haw.	Australian pest pear	Thicket-forming, cladodes are longer than broad; spines are straight, flattened and yellow	Most common in arid and semi arid areas, disturbed and open areas, rangelands, conservation areas, roadsides, wastelands, grasslands, coastal bush lands, dry gullies and river banks

negatively on human and livestock health. On the other hand, *O. elatior* is less widespread but capable of forming dense thickets in the arid and semi-arid areas [26]. *Opuntia ficus-indica* is another serious invasive species that has destroyed grazing land in the Kenyan and Tanzanian drylands [28]. Some studies have discovered that the species is the most diverse in the Rift Valley and Eastern areas of Kenya [29]. Another species *Opuntia engelmannii* is naturalized and invasive in South Africa and Kenya [30]. The species is prohibited in South Africa and should be controlled in all situations [31] while in Kenya it is not yet declared as a weed but has invaded several ecosystems especially in Baringo and Laikipia [30]. The species starts as a minor weed in localized areas but later explodes in abundance causing invasions in wider areas [25]. In addition, the species is fast-growing and forms impenetrable spiny thickets that overwhelm native vegetation and prevent free movement of people and animals [30]. *Opuntia monacantha* is widespread in Kenya but is not particularly common. The species is scattered in Laikipia, Baringo, along the Coast and Narok. It is also naturalized in other parts of the world, including Australia, South Africa and south-eastern USA. The species is reported as a problem by spreading rapidly especially on degraded rangelands, disturbed areas and agricultural land [30]. Large infestations of *Opuntia exaltata* are found in parts of Nakuru and Naivasha. The species displaces native plant species, lowers the value of pasture and prevents free movement of people, livestock and wildlife. *Opuntia exaltata* is listed as a noxious weed in South Africa [32]. All *Opuntia* species in Kenya are spiny except *Opuntia microdasys* which has no spines but many glochides. It rapidly establishes large and dense infestations that prevent access to water and other resources [26]. The species has a high frequency of vegetative multiplication that can develop dense populations that readily colonize new and wide areas [33].

Pathways and risks

Three main pathways of *Opuntia* introduction in Kenya are identified according to the CBD (Convention on Biological Diversity) [34]: (i) intentional introduction as ornamentals but escapes unintentionally, (ii) unintentional introduction through natural dispersal and (iii) unintentional introduction through transportation of habitat material from the infested areas to new areas. However, most introduction pathways in the arid and semi-arid areas of Kenya are due to intentional introductions for ornamental purposes. This is because cactus plants are very popular in the

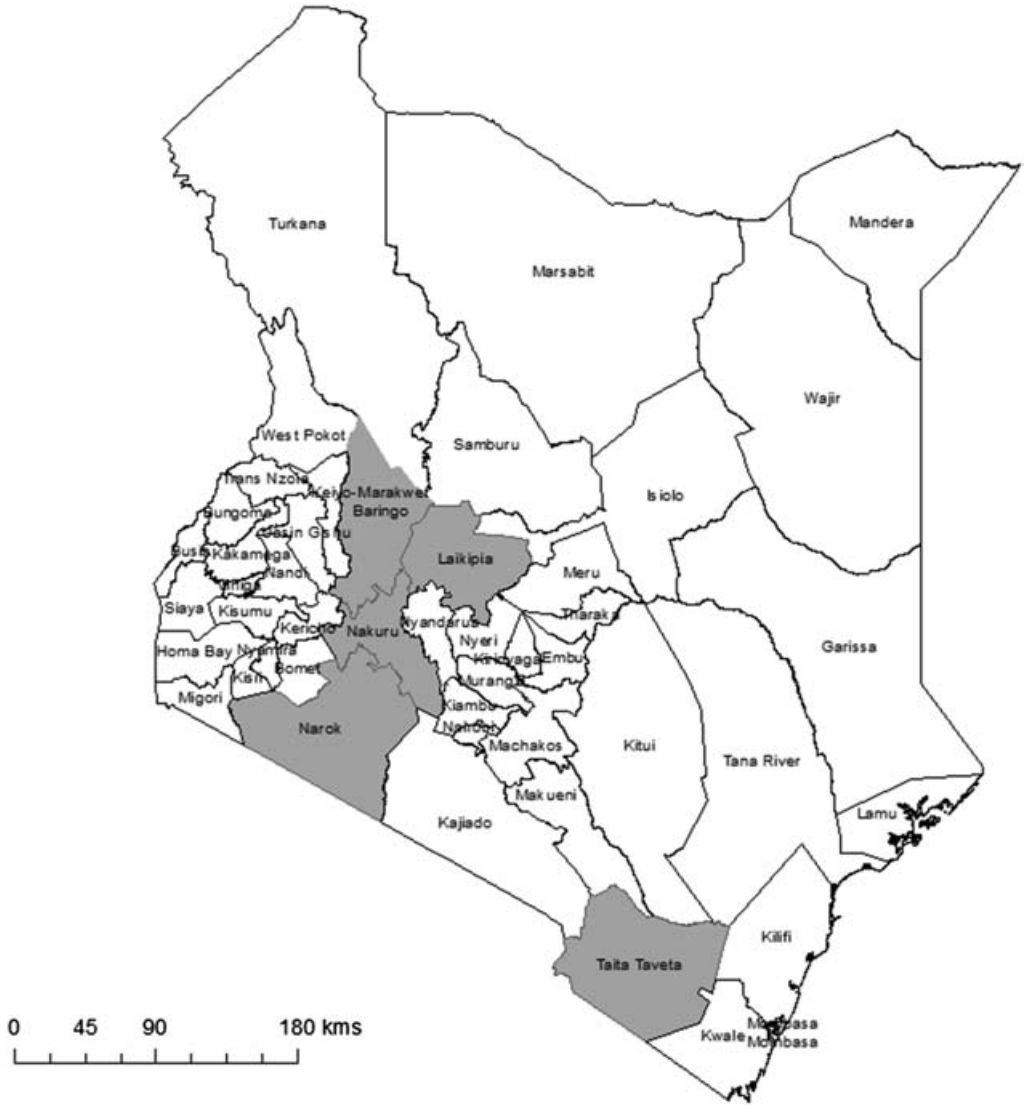

Figure 1 Major areas of *Opuntia* invasion in Kenya.

horticultural trade. This trade has developed over the years and is responsible for the spread of many IAS that have had devastating effects on people and livelihoods [8, 27]. Horticultural trade of *Opuntia* continues in Kenya and should be regulated and monitored to prevent further spread and future invasions. The escape is from cultivation especially through garden throw-outs [35] while dispersal is through vegetative reproduction [16], floods [36] and rapid dispersal of seeds by various vectors [18]. A study in the Serengeti–Mara ecosystem of East Africa revealed that more than 80% of alien plants were intentionally introduced with 24% having established naturalized populations and spreading rapidly in areas far away from human settlement, hence posing a major threat to biodiversity and tourism [37]. Such pathways and their associated vectors require proper management to limit the movement and subsequent invasions. Strategies for control and management include increased public awareness of the risks of invasions, screening of seed imports at boarders and promotion of safer non-invasive plant species for ornamental purposes.

Based on the impact category [34], four of the species; *O. stricta*, *O. ficus-indica*, *O. engelmannii* and *O. monacantha* were the most widely distributed and of major concern. *Opuntia elatior*, *O. exaltata* and *O. microdasys*, on the other hand, were of minor infestations and of moderate concern. All these species belong to category E of the unified framework for biological invasions where they are fully invasive with individuals dispersing, surviving and reproducing at different sites across many habitats [38]. But a significant correlation exists between population size and impact where cacti with larger population size are more likely to cause substantial impacts [39]. However, an invasive plant species with limited distribution can still have greater impacts than an abundant widespread invader if no urgent management actions are put into place.

This can cause massive irreversible community changes and extinctions.

Negative impacts of Opuntia

Despite that *Opuntia* plants are appreciated for both direct and indirect uses by many livelihoods in the world [19], the species is hardly used in Kenya due to the presence of spines and glochids that cause injuries to both human and animals. They are only valued for their use as ornamental plants or as a live hedge. However, these uses cannot compensate for the overall negative impacts they portray. Once they escape into the environment, they usually adapt to a broad range of environmental conditions where they are widely established. *Opuntia* species mainly invade the natural pasture which forms about 80% of the Kenyan land mass. Pastoralists are the main inhabitants of these lands and contribute more than 50% to agricultural Gross Domestic Product (GDP). However, the loss of productivity, stability and ecological functioning of these lands by IAS hinder the economic development [40]. In many African countries, forage losses to unpalatable invasive plants have reduced rangeland capacities to three-folds [2]. The potential costs associated with *Opuntia* invasion in the rangelands are based on reduced grazing land, replacement of native forage species as well as negative impacts to human and livestock health [27]. Infestation of invasive plants also influences the availability of products by reducing the abundance of native plant species, which in turn affect the ecosystem services [41]. In addition, invasive weeds alone are responsible for reducing overall crop yields by not less than 25% with extreme cases of more than 75% [2]. Some studies have assessed the socio-ecological impacts of *Opuntia* in Eastern Africa and have reported that the species invade valuable grazing land, reduce native plant populations and rangeland condition, affect human health and impede the mobility of human and animals [27]. Although the full cost of the impacts of cactus invasions in Kenya has not yet been quantified, some studies show an average economic loss of US$ 500–1000 per rural household per year [27].

Very few households in the rural areas are actively involved in managing the species hence revealing the need for management interventions [27]. Nevertheless, many invasion opportunities follow disturbances that are largely caused by human activities and include intensive grazing and land clearance for agriculture [42]. These later degrade the lands and open opportunities for exploitation of invasive trees and shrubs [10]. *Opuntia*, in particular, invades areas that have experienced large land-cover transformations especially in woodlands and bushlands located near urban areas [43]. At the ecosystem level, invasive alien plants change community structure and composition and their eradication may open niches for the establishment of other undesirable plants unless restoration practices are incorporated [44].

Effective control measures

The most applied methods of managing *Opuntia* in Kenya are mechanical and manual methods such as chopping, burying and burning. This is because they are target specific and economical [40]. However, they can be labour-intensive in large-scale infestations and the disturbed areas may encourage re-invasion [4]. Herbicides, on the other hand, improve the effectiveness of chopping but their use alone is very ineffective since the plant regenerates after some time. This is a major drawback in the use of herbicide especially where populations are replenished from soil-stored seeds [45]. Besides, herbicides are very expensive, do not give long-term effects and can lead to the replacement of sensitive species as well as resistance after continuous use [4]. The control of *O. stricta* is almost entirely reliant on biological control with two effective natural enemies; *Cactoblastis cactorum* Berg and *Dactylopius opuntiae* Costa [46]. The latter was introduced in a pilot project in Laikipia, Kenya and showed a positive result. The main benefits of biocontrol are that they are cost-effective, permanent and include areas which are not accessible for chemical or mechanical control [47]. However, a study conducted after the biocontrol trial revealed that reduction of *O. stricta* populations affected the native baboon-plant mutualism where the baboons had to supplement their diets with other plant species [48]. Biocontrol species may also become invasive and negatively impact non-targeted species [49]. Besides, removal of invasive plant species by chemical, mechanical or biocontrol methods may open niches for other invasion unless followed by rehabilitation [11, 43]. Instead of relying on a single control method, successful management of IAS requires an integrated approach that uses multiple control methods to prevent re-invasion and improve ecosystems.

Regulations to prevent introductions

The threats of invasive cactus are part of many pressures and drivers of biodiversity loss and environmental change and therefore cannot be treated in isolation. The responses should, therefore, be long-term and addressed at various scales. Regardless of the many laws and institutions governing the management of invasive species in Kenya, invasion of plant species continues as a threat and key contributor to environmental degradation as a result of movement of plant materials [28]. Most policies addressing invasive species focus mainly on well-established invasive species despite the fact that prevention and eradication of invaders with limited distribution are more cost-effective [50]. Effective policies are therefore needed to prevent an increase in the significant negative impacts caused by invasive species including those that are not well established and with limited distribution [51]. Nevertheless, addressing the problem wholesomely can start by categorizing IAS into groups of invasive, prohibited and permitted lists [52].

Grouping species for management identifies not only common goals but also common stakeholders and allows simplification of decision-making processes [32]. Other regulations include constricting pathways, intercepting movements at borders and assessing risk for intentional imports [50]. Generally, unintentional introduction of any invasive plant into Kenya is quarantined based on risk analysis and existing scientific knowledge on the distribution, biology and pests of the plant [53]. Inspections are also carried out at the entry points; sea ports, international airports and borders [53]. For the intentional introduction of bioproducts, risk assessment is first carried out and those approved for introduction are referred to relevant research institutions for efficacy or registration. However, appropriate measures on the monitoring, control or elimination of these species are required. Furthermore, laws and regulations for prohibiting the introduction and use of such species should be enforced and maintained.

Conclusion

Seven species of *Opuntia* have been identified in Kenya and they share the same traits. Their introduction is largely intentional and attributed to changes in land use. The most applied methods of managing *Opuntia* are mechanical and chemical methods that are unsustainable. To properly manage *Opuntia* in the country, mapping and inventory of the species in all the counties are necessary together with community awareness on the effects of invasions and possible solutions. Furthermore, effective policies are required to prevent an increase in the significant negative impacts caused by IAS including those that are not well established and with limited distribution.

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