Institutionen för skoglig vegetationsekologi
SLU
901 83 UMEÅ

Spread of the introduced tree species *Prosopis juliflora* (Sw.) DC in the Lake Baringo area, Kenya

Stefan Andersson

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Institutionen för skoglig vegetationsekologi
Sveriges lantbruksuniversitet
901 83 UMEÅ

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PREFACE

This study was initiated by Pia Barklund at the World Agroforestry Center (ICRAF) in Nairobi in 2003. The study was funded by the Swedish International Development Cooperation Agency (Sida) and was carried out as a Minor Field Study. The field work was conducted in Kenya during February – May 2004 with the assistance from ICRAF and local people in the area.

ABSTRACT

The spread of the introduced plant *Prosopis juliflora* (Sw.) DC was studied in the Lake Baringo area in Kenya. In addition, woody plant diversity and soil characters were studied. Major initial planting sites with *P. juliflora* were located and marked with GPS. The number of major plantations was 16 and obvious signs of spread were found from 9 of the plantations. Sites planted with *P. chilensis* were found as well, but no signs of spread were observed. Small scale plantations with *P. juliflora* and *P. chilensis* were also located. Observations of spread by *P. juliflora* were made both from major planting sites and from small scale plantations. *P. juliflora* showed the strongest signs of spread along roads and in areas where the soil had a fine texture and where there was seasonally or permanently good access to water. The abundance of plant species was low in the area and 31 species were scored during the inventories. However, the sampling was not large enough to capture the whole species pool. Plant diversity was slightly higher where *P. juliflora* was absent. Soil samples showed a high pH and the highest was detected in Loruk in the northern part of the study area. Loruk also had the highest amount of exchangeable potassium and the coarsest soil. The invasion of *P. juliflora* seemed higher in areas where no previous vegetation existed and in areas with high water accessibility. Some indications also showed that slopes and coarse soil texture was unfavourable for *P. juliflora*.

Keywords: Africa, invasive species, leguminosae, spread, mapping.

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INTRODUCTION

Exotic plant species have been introduced world wide due to their economic, environmental or aesthetic values. Some accidental introductions have also occurred through time. Nevertheless, introduction of new species is not always a success and one of the problems linked to this is the possibility of these species becoming invasive. The invasive 'aliens' often have negative economic, environmental and/or social impacts. These include reduction of grazing areas, reduction of crop yield, risk of threat to biodiversity, disruption of water flow, livestock poisoning and the formation of impenetrable thickets.

The economic impact from introduced species can thus carry a heavy price tag. It was estimated in 2000 that the United States' total costs from invasive plant species was US$ 24 billion per year (Pimentel *et al*. 2000). Eradicating invasive alien plant species is also very costly. An attempt was made in Mauritius during the 1980s to eradicate exotic plants from 11 different plots. The total area of these plots was 57.9 ha and only the initial costs of clearing the plots were around US$ 10 000/ha. The costs of subsequent weeding (three times a year) in the areas were US$ 2000/year and only after four-five years could the frequency of weeding gradually be reduced (Dulloo *et al* 2002).

Far from every exotic plant species become invasive weeds. Only a small amount of introduced plant species form viable stands/populations and even fewer naturalize to the new environment. It has been estimated that one or two percent of introduced exotic plants become invasive weeds (Groves 1986). However, it is difficult to predict whether a plant species has the ability to spread uncontrollably. A common phenomenon with introduced plant species is a so called 'time lag', where the plants only start to show invasive tendencies after a period of years to many decades (Hughes 1994, Mooney & Cleland 2001). There are three main strategies to control or eradicate invasive species: Physical, where plants are mechanically removed, chemical where herbicides are used against plants, and biological, where predators or pathogens are used to control the invading plant's reproduction (Hobbs & Humphries 1995, Geesing *et al* 2004).

Prosopis juliflora (Sw.) DC. is an evergreen tree native to northern South America, Central America and the Caribbean (Pasiecznik *et al* 2004). It is fast growing, nitrogen-fixing and tolerant of arid conditions and saline soils (Anonymous 2003, Pasiecznik *et al* 2004). *P. juliflora* has a large crown and an open canopy and can grow to a height of 14 meters (Anonymous 2003). Its stem is green-brown, sinuous and twisted with axial and strong thorns (Figure 1). Its bark is red-brownish and rough and the root system has a deep taproot

Figure 1. Thorn of *P. juliflora*.

that allows the tree to reach deep water tables. The leaves are compound (Figure 2), dark bluish-green and have high tannin content (Pasieczcznik *et al* 2001, Matthews & Brand 2004). The foliage is unpalatable for livestock, except for very tender new shoots (Anonymous 2003). *P. juliflora* flowers throughout the year with yellow flowers hanging from the branches. Its fruits are pods, which are green when immature and turn yellow when they mature (Masilamani & Vadivelu 1997). The pods contain a high level of sugar (Talpada & Shukla 1988, Batista *et al* 2002) and are palatable to livestock when ripe (Anonymous 2003). A mature *P. juliflora* tree can produce 40 kg of pods per year, from which 60 000 seeds can be obtained (Alban *et al* 2002).

Figure 2. Leaves of *P. juliflora.*

In Kenya *P. juliflora* was first planted in the beginning of the 1970s to rehabilitate a quarry in Bamburi near Mombasa (Ebenshade & Grainger 1980, Maghembe *et al* 1983). In the early 1980s *P. juliflora* was introduced in the Lake Baringo area through the Fuelwood Afforestation Extension Project (Kariuki 1993, Lenachuru 2003). The major objectives of the project was to involve the local people in tree planting to overcome problems such as lack of firewood and overgrazing (Kariuki 1993, Lenachuru 2003). The project was implemented in two phases, from 1983 to 1985 and from 1987 to 1990 (Kariuki 1993). *P. juliflora* was tried and found to be suitable for the lake Baringo area together with other exotic tree species such as *Prosopis chilensis*, *Senna siamea*, *Azadirachta indica* and *Albizia lebbek* and also a number of indigenous species such as *Acacia tortilis*, *Acacia nilotica*, *Acacia albida*, *Salvadora persica*, *Parkinsonia aculeata*, *Cordia sinensis*, *Balanites aegyptica* and *Terminalia brownii* (Lenachuru 2003).

In the initial stage *P. juliflora* was appreciated due to its ability to grow where nothing else seemed to be able to grow. It was easy to plant, prevented soil erosion and sandstorms, provided shade and its pods served as a source of food for livestock (Lenachuru 2003). After about ten years problems with *P. juliflora* started to occur. It started to spread rapidly and its ability to survive cutting by coppicing made it uncontrollable. People are today complaining about the shrub forming impenetrable thickets that are preventing other plants from growing. Furthermore they claim that their goats get bad teeth (Figure 3) after eating the sugary pods from the trees, which leads to teeth loss and thus starving goats. However, that has not been documented. Other complaints about *P. juliflora* are that its thorns are causing injuries on people and livestock and punctures on vehicles (Lenachuru 2003).

Objective

The problems with *P. juliflora* need a solution. Some people even suggest an eradication of the tree. The main issue is the spread and if it could be controlled, a solution would be near. The objective for this project was to map the initial planting sites around Lake Baringo and to determine the rate of spread at different sites and also to quantify the abundance of indigenous plant species in and around initial planting sites of *P. juliflora*.

Figure 3. Goat with plant rests stuck in between its teeth.

MATERIALS AND METHODS

Study area

The study was done in Baringo District in the area around Lake Baringo (0°33'N, 36°04'E), which is located only some 50 kilometres north of the equator (Figure 4). The altitude of the study area ranged between 900 and 1200 metres above sea level. The climate is semi-arid (Owen *et al* 2004) and the average minimum and maximum temperatures are 20º and 30ºC respectively (Kassilly 2002). The area has two rainy seasons and the mean annual rainfall is 635 mm (Kassilly 2002). The vegetation in the area is bushy and characterized by indigenous species *Acacia spp.*, *Acalypha fruticosa*, *Maerua edulis* and the exotic species *Lantana camara*. The soils in the area are mainly moderately to poorly drained, very deep, strongly calcareous, saline and sodic. The texture is fine sandy loam to clay (Anonymous 1987).

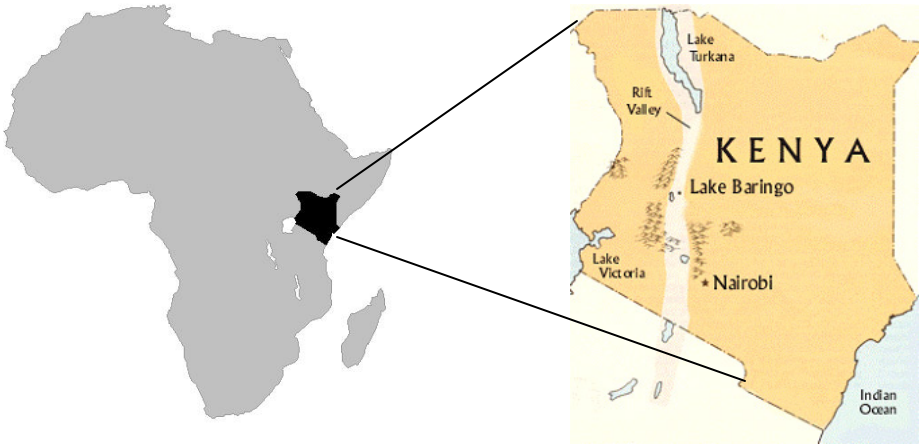


Figure 4. Maps showing the locations of Kenya and Lake Baringo.

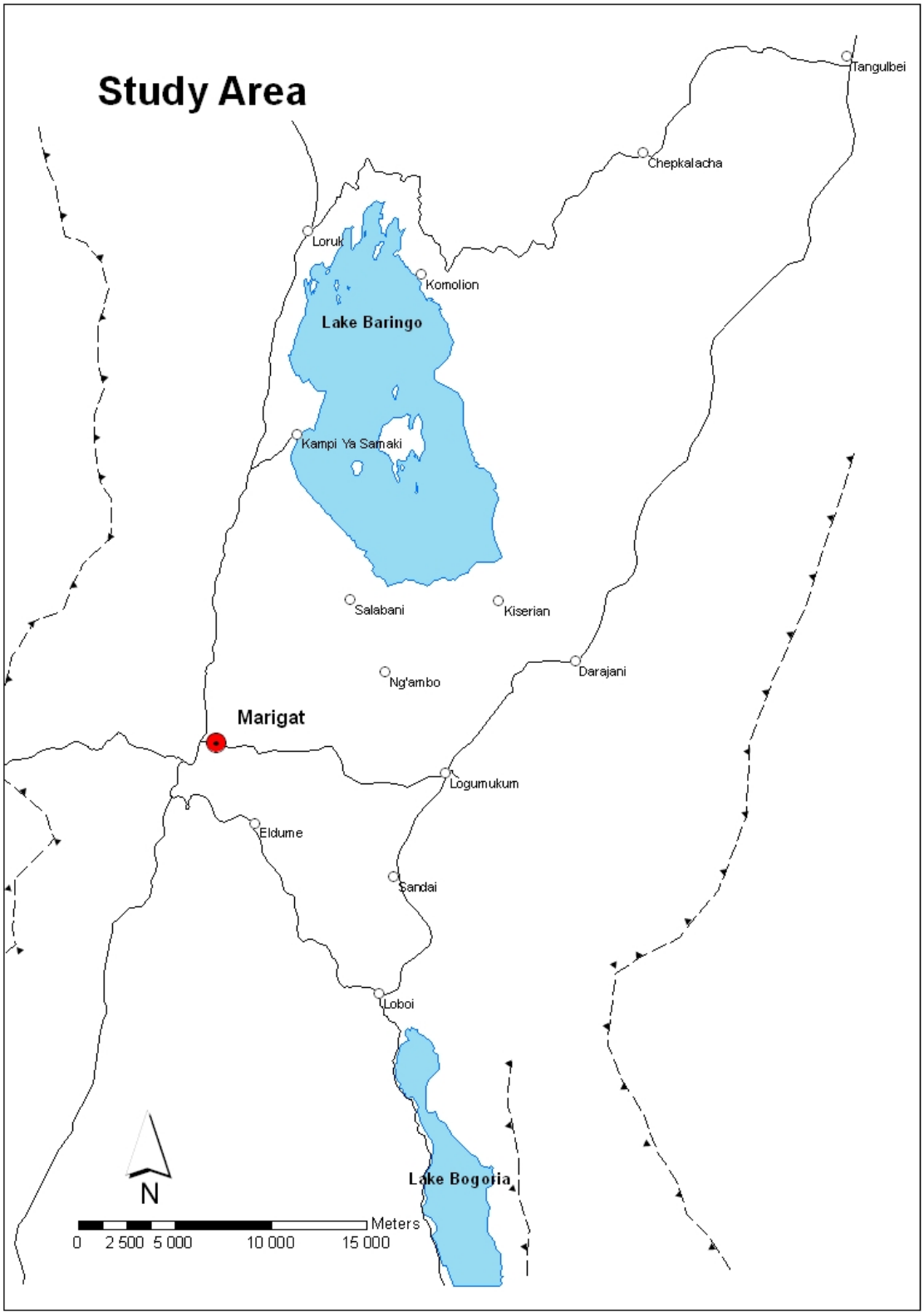


Figure 5. Map over the study area.

Lake Baringo is named after the Ilchamus word ‘mparingo’, which means lake (Lepariyo pers.comm. 2004). Three major ethnical groups live in the area: Tugen, Ilchamus and Pokot. The Tugen live in the hilly western area, the Ilchamus live in the south eastern plains (Njemps flats) and the Pokot live in the north part of the area. The population in the area was estimated in 1999 to 54 200, the number of households to 9850 and there were 178 villages. The number of livestock was estimated at 68 000, of which half the number were cattle and the other half were sheep and goats (Tokida 2002).

The area for this research (Figure 5) stretches from latitude 0°18.836N to 0°48.074N and from longitude 35°56.210E to 36°17.372E. Three sites were chosen to represent different characteristics in the area. The site with the least spreading of *P. juliflora* was in Loruk (0°43.817N, 36°01.829E), which is a very dry area with eroded igneous stones and bushy vegetation. A site with a moderate spread was located in Eldume (0°26.903N, 36°01.401E), a dry area with alluvial clay soils and scarce and patchy vegetation. The site with the most severe spreading of *P. juliflora* was in Ng’ambo (0°30.449N, 36°04.000E), a dry area with alluvial clay soils where no vegetation exists apart from *P. juliflora*.

Mapping the distribution

The initial planting sites of *P. juliflora* were shown by local people. A GPS (Silva Multinavigator version 2.11) was used for marking waypoints where initial planting sites were located and in some cases where *P. juliflora* had spread. In each major planting site waypoints were marked to demarcate the area where *P. juliflora* had been planted. Observations about vegetation and other conditions were recorded during the time of mapping. One site in Rugus, northeast from the lake, could not be reached due to floods that had damaged the roads. In that site *P. juliflora* was said to have been planted. This was never confirmed due to the inaccessibility of the planting site.

Plant inventories

The plant inventories were made in the three selected sites: Loruk, Ng’ambo and Eldume. In Loruk and Eldume a centre point of the planting site was calculated from the waypoints collected earlier. In Ng’ambo three sites had been planted adjacent to each other and therefore a centre point was estimated from the three different sites. From each centre point four transects were made, one in each cardinal direction: north, south, west and east. By standing in the centre point and using a magnipointer function in the GPS the correct waypoints for the planned quadrates of the plant inventories were marked.

Along each transect, six 10 x 10 m quadrates were laid out with 500 meter intervals. At Loruk only three quadrates were made in each direction since there was no spread by *P. juliflora*. In each quadrate all woody plants with a root collar diameter of 1 cm or more were counted and identified to species. Root collar diameter was measured 5 cm above ground on three plants of each species. The eastern transect in Ng’ambo had to be cut

short at 1385 meters from the centre point due to impassable terrain. However, a last quadrate was established there.

Soil sampling and analysis

Soil samples were taken from three areas: Loruk, Ng'ambo and Eldume. In each area soil samples were taken at two sites: Inside an initial *P. juliflora* plantation and some 500 metres away from the same plantation. At each site twelve soil samples were taken of a 30 cm depth of top soil with a 3 cm in diameter auger. The twelve samples were mixed in a bucket to give a combined sample for each site, making a total of six combined samples. The combined samples were put in plastic bags and taken to World Agroforestry Centre (ICRAF) in Nairobi for analysis. The methods and equipment used for determination of the various soil chemical parameters were: pH (Dry Soil Routine Analyses), soil particle (Hydrometer Method), Nitrogen (Kjeldahl digestion), Phosphorus and exchangeable Potassium (Olsen) and organic Carbon (Colorimetric Method).

RESULTS

Mapping the distribution

A total of 37 initial *Prosopis sp.* planting sites were identified. These included sites where both *P. juliflora* and *P. chilensis* were planted. Out of 37 sites, 16 were found to be major *P. juliflora* planting sites while 17 were small scale plantations of both *P. juliflora* and *P. chilensis*, essentially planted for ornaments, soil erosion control and to create shade. Four larger sites with *P. chilensis* were found.

Major *P. juliflora* plantations

Loruk

Loruk is located northwest from Lake Baringo and two major initial planting sites were found in this area. The sites are numbered 1 and 2 (Figure 6) and the areas of the plantings were 7.8 and 52.4 ha respectively. The area was dry and flat and showed no signs of erosion. The soil was coarse and volcanic rocks were abundant. Both sites were planted in rows together with other tree species and at none of the sites did *P. juliflora* show any signs of spread. The *P. juliflora* trees had a good survival rate in both plantations and the height of the trees were between 0.5 and 5 metres. Some *P. juliflora* trees had

Figure 6. Initial planting sites 1 and 2 in Loruk.

branches cut off at waist height, probably for firewood. The cut trees had either died from draught or were resprouting. Most of the *P. juliflora* trees were multi-stemmed and the root collar diameter ranged from 5 to 30 cm. At site 1 the density of *P. juliflora* was higher than at site 2. However, the mean height of the *P. juliflora* trees was lower at site 1 than at site 2.

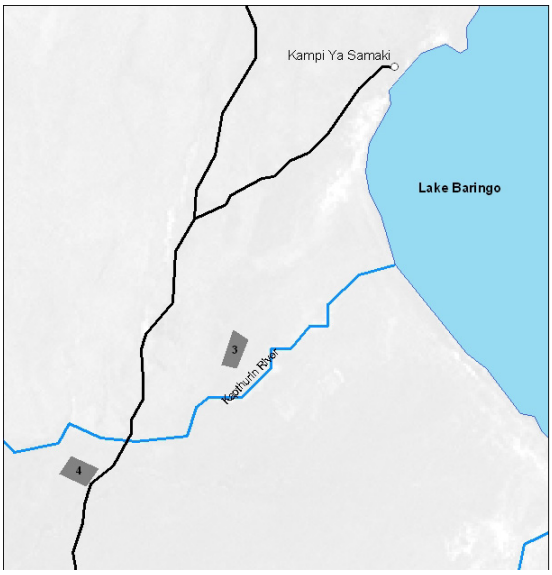


Figure 7. Sites 3 and 4 by Kapthurin River.

Kapthurin River

Two initial *P. juliflora* planting sites were located west from Lake Baringo close to the seasonal Kapthurin River. The sites are numbered 3 and 4 (Figure 7) and the areas of the sites were 8.5 and 9.5 ha respectively. Both sites had a low survival rate of *P. juliflora*, which seemed to have been planted along with other tree species. At site 3 there was a severe dieback of the planted trees and no spread was seen from *P. juliflora*. The vegetation in and around the site was bushy. At site 4 there were very few *P. juliflora* trees left and the remaining trees seemed to have dried up and were now resprouting from the lower stem. The height of the *P. juliflora* trees ranged from 2.5 to 5 metres and many of the remaining trees were cut for firewood at waist height.

Salabani

At Salabani Secondary School one initial *P. juliflora* planting site was located and numbered 5 (Figure 8). The area of the plantation was 25.7 ha and *P. juliflora* was spreading in the area. The *P. juliflora* trees at the site were removed to build a secondary school and only a small plot of *P. juliflora* was left in the southeast section of the site. The density was very high where *P. juliflora* was not cut and the trees have a height of approximately 4 metres. The community had put a lot of work into removing the *P. juliflora* trees and local people informed that resprouting shoots had to be removed several times. The site now serves as a school yard.

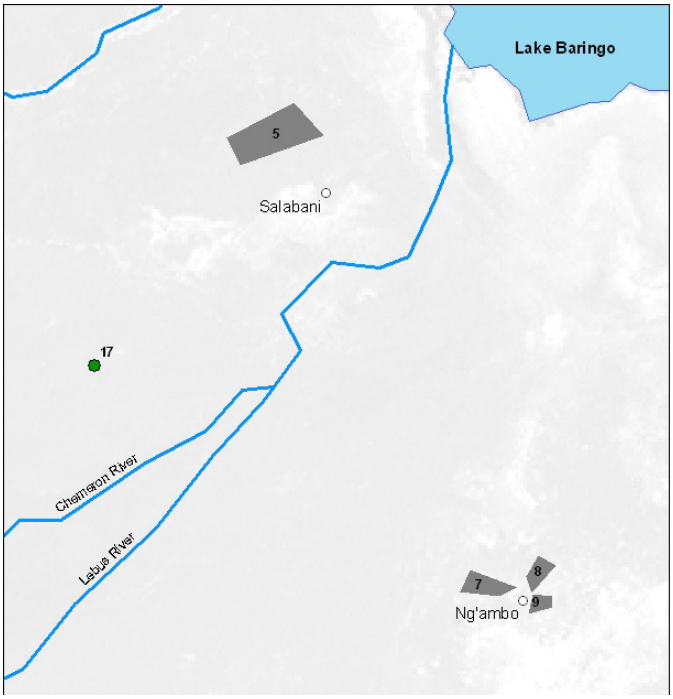


Figure 8. Planting sites 5, 7-9 and 17.

Chemeron dam

Around the Chemeron dam a *P. juliflora* planting site was located. The site is numbered 6 (Figure 9). *P. juliflora* was very abundant around the dam and it was planted without fencing, to control erosion and to prevent evaporation. The dam was made for irrigation and had an area of 100 ha, but was dried out at the time of the inventory. There were many other tree species in the area and the height of the trees was up to 5 metres. *P. juliflora* had spread in all directions.

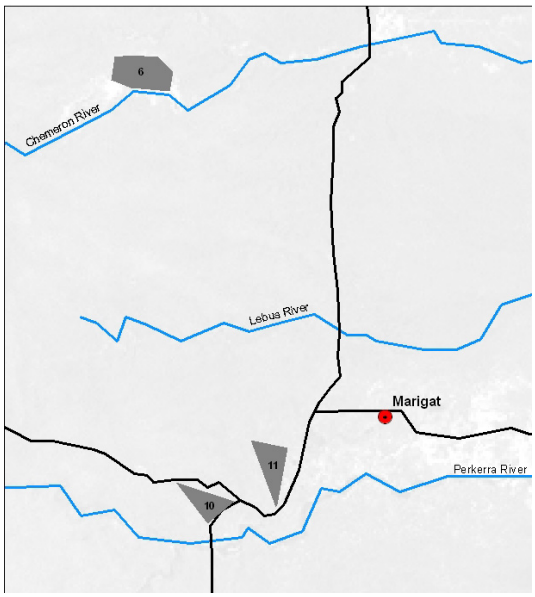


Figure 9. Planting sites 6 and 10-11.

Ng'ambo

Three sites were located very close to each other in Ng'ambo. The sites are numbered as 7, 8 and 9 (Figure 8) and the sizes of the sites were 7.1, 4.5 and 3.0 ha respectively. In Ng'ambo the soil had a very fine texture and after rains the area is flooded. One kilometre east from the sites the area was wet even during the dry periods. *P. juliflora* showed a very high rate of spreading and had formed dense thickets in and around the initial planting sites. The height of *P. juliflora* ranged from fresh seedlings up to trees of 9 metres in the area and the maximum diameter was over 20 cm. In all four cardinal directions *P. juliflora* had spread over three kilometres from the initial planting sites.

Marigat

Two initial *P. juliflora* planting sites close to Marigat were located and are numbered 10 and 11 (Figure 9). The sizes of the plantations were 12.9 and 16.2 ha respectively. Both sites were situated on dry and elevated sites with stony texture. *P. juliflora* showed no signs of spreading and was not dominating at any of the two sites. The dominating vegetation at both sites was *A. mellifera*, which might have been planted together with *P. juliflora*. The mean height of the vegetation at both sites was three metres and there was a good coverage, mainly from *A. mellifera*. *P. juliflora* was not seen growing in slopes but was abundant in flatter parts of the sites.

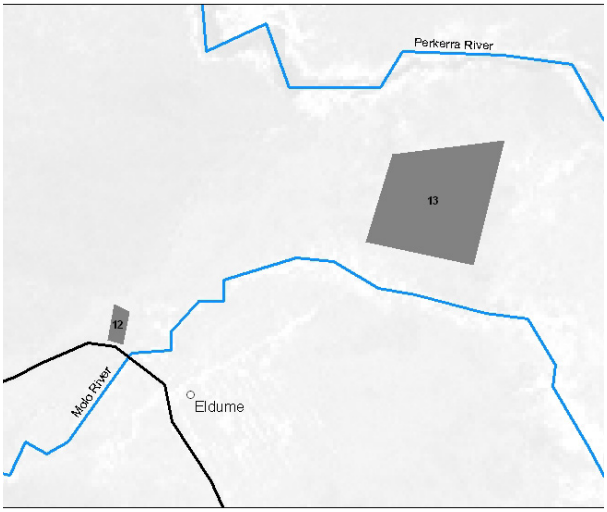


Figure 10. Initial planting sites 12 and 13 in Eldume.

Eldume

Eldume is located south from Marigat and on the southern side from Perkerra River. Two major *P. juliflora* planting

sites were located not far from each other in Eldume. The sites are numbered 12 and 13 (Figure 10) and the area showed signs of flooding after rains. There were homesteads in and around the initial planting sites and goats were roaming in the area.

Site 12 was located next to a crossing between Molo River and the main road running towards Lake Bogoria. The size of the site was 3.6 ha, which made it one of the smallest major planting sites. There were major erosion damages (Figure 11) on both sides of the road, next to the planting site. The site was said to have been planted in 1996 and no spread from the site could be seen. The height of the planted *P. juliflora* trees ranged from 1.5 metres up to 5 metres. The lower *P. juliflora* were bushy and mainly on the western side while highest trees were growing on the eastern side of the plantation. There were both pods and flowers abundant on the *P. juliflora* trees, so spreading of the trees from this planting site is fully possible to occur in the nearest future. Fresh seedlings were seen inside the initial planting site.

Figure 11. Erosion damages in Eldume.

Site 13 was the largest initial *P. juliflora* planting sites and was located two kilometres northeast from site 11. Its size was 72.3 ha. The site showed big differences in height, survival rate and density of *P. juliflora*. The soil was fine in the western area of the site while in the eastern part it was coarser, due to flooding. There was a big invasion of *P. juliflora* in the area west from the initial plantation. There was also *P. juliflora* spreading south, west and north from the initial plantation, but at a more moderate rate. The vegetation was however very patchy in the area both with *P. juliflora* and other plant species. In the northwest area of the site the density of *P. juliflora* was the highest and the height of the trees was approximately 4 metres. This was also the only area in the site

where *P. juliflora* had formed a closed canopy. The lowest density of *P. juliflora* was in the south-eastern part of the plantation, where the most severe signs of flooding also was seen. The highest *P. juliflora* trees were found outside the closed canopy and had a height of up to 9 metres. South from the site Molo River was running and along the river there were plenty of large *Acacia*-trees. *P. juliflora* had spread even among the *Acacia*-trees. Some *P. juliflora* trees had been cut for firewood and were resprouting both inside and outside the plantation.

Logumukum

East from Loboi River, in Logumukum an initial *P. juliflora* planting site was located and numbered 14 (Figure 12). The size of the site was 9.9 ha. *P. juliflora* was only abundant in the north and northeast area of the site. Elsewhere the plantation seemed to have dried out. Spread from the planting site could be seen along the road both to the east and to the west.

Sandai

In Sandai one initial *P. juliflora* plantation was located and numbered 15 (Figure 12). The size of the plantation was 4.3 ha. Deep eroded scars from flooding were crossing the area. There were very few *P. juliflora* seen in the plantation and no apparent spread was observed.

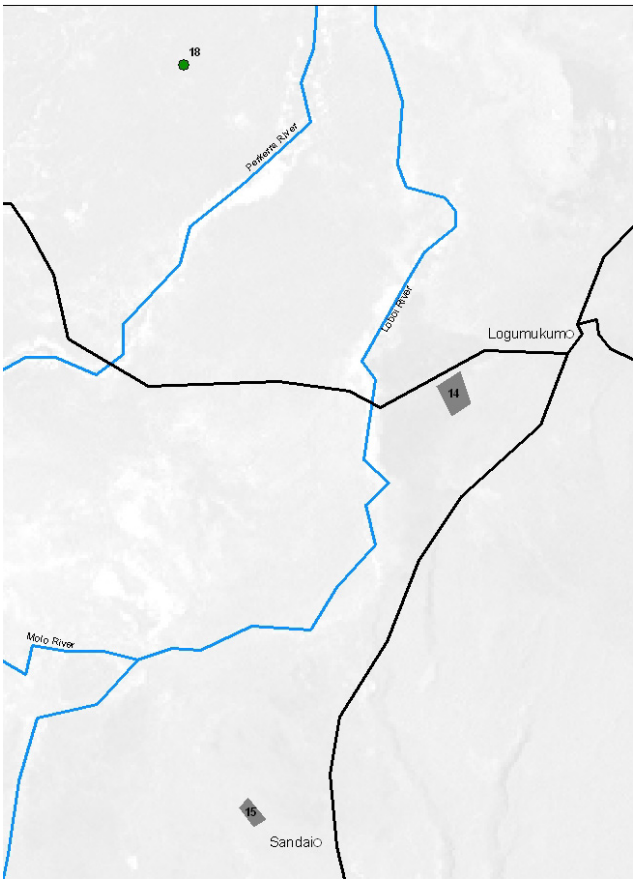


Figure 12. Sites 14-15 and 18.

Loboi

Loboi is located 1.5 kilometres north from the northern end of Lake Bogoria. One initial *P. juliflora* plantation was located in Loboi. It is numbered 16 (Figure 13) and had a size of 13.3 ha. *P. juliflora* was spreading from the plantation. The mean height of planted *P. juliflora* was 2 metres and some cutting was seen. Fresh shoots on *P. juliflora* had also been browsed by animals. There were cattle, goats and Thomson's Gazelles seen in the area. Signs of flooding were abundant and some *P. juliflora* bushes were seen growing where flooding had occurred. *P. juliflora* was most dense in the middle of the plantation.

Larger *P. chilensis* plantations

Ildepe

An initial planting site with *P. chilensis* and *Cordia sinensis* was located in Ildepe. The site has number 17 (Figure 8) and the area was 4.9 ha. All the planted trees were dead and a few seedlings of *P. juliflora* had invaded the site.

Sintaan

In Sintaan one planting site with only *P. chilensis* was located. The size of the site was 1.6 ha and it is numbered 18 (Figure 12). The area was dry and no spread of the *P. chilensis* trees was seen.

Kapkuikui

Next to the main road in Kapkuikui a stand of *P. chilensis* was located. The site has number 19 (Figure 13). The height of the trees was 8-10 metres and the diameter was 10-40 cm. The trees were erect and suitable for saw timber and no grass was growing in the stand.

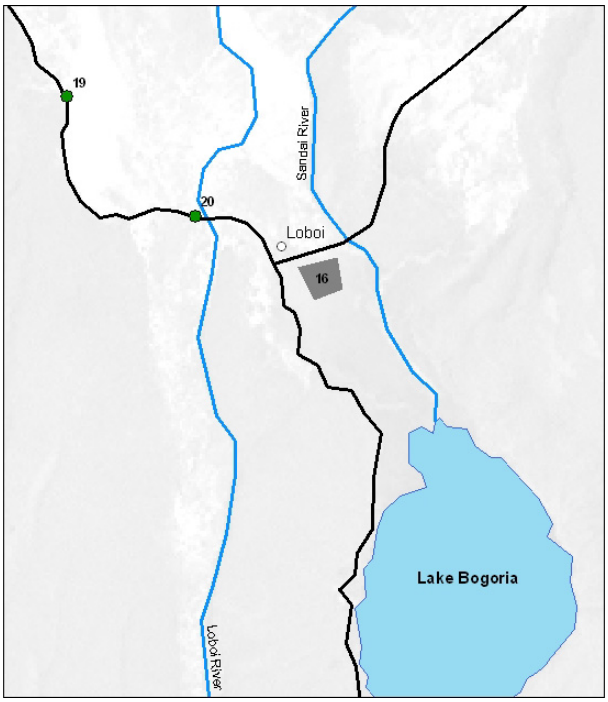


Figure 13. Sites 16 and 19-20 in Loboi.

Loboi

Adjacent to Loboi Riverside Camp a plantation with *P. chilensis* was located and numbered 20 (Figure 13). The plantation was still fenced and the trees seemed planted later than the *P. chilensis* trees in Kapkuikui.

Small scale plantations

In and around central Loruk *P. juliflora* was seen at homesteads and sparsely along the roads. At Loruk Police Station *P. juliflora* was planted for ornamental reasons and had not been spreading. The police station is located on an elevated site close to a bay of Lake Baringo.

In Komolion, a village by the eastern shore of the northern lake, *P. juliflora* was planted for ornamental reasons. Fresh seedlings were immediately cut by the locals. In the villages of Chepkalacha and Tangulbei (13 and 25 km northeast from the lake respectively) *P. juliflora* and *P. chilensis* was planted to prevent erosion and evaporation from small dams. In Chepkalacha trees were planted to create shade beside a primary school and few trees had spread into the village. In Tangulbei a few trees were planted at Tangulbei Catholic Mission, but no spread was seen in the area.

In and around Marigat *P. juliflora* was abundant along roads and homesteads. The trees had been planted together with many other tree species for ornamental reasons and to provide shade. *P. juliflora* was spreading at a high rate in the area causing many annoyances to local people and livestock.

North from Lake Bogoria *P. juliflora* was planted by Bogoria Hotel for ornamental reasons and in Sandai as windbreak. Both *P. juliflora* and *P. chilensis* was also planted in small scales at primary schools all over the study area with only occasional signs of spread.

Other observations of P. juliflora invasion

In Kampi Ya Samaki *P. juliflora* had formed a dense population at the shore of Lake Baringo. The trees were up to 6 metres high, multistemmed and had grown even into the lake. Further up from the shore *P. juliflora* became less dense and the last tree was seen 1100 metres from the shore of the lake.

Figure 14. Dense and bushy *P. juliflora* spreading along the road between Kampi Ya Samaki and Marigat. The larger trees are mainly Acacia species.

Along the main road between Kampi Ya Samaki and Marigat *P. juliflora* could be seen spreading from Chemeron dam and had formed dense and bushy populations, mainly next to the road (Figure 14). Northwards the spread along the road seized as the road crossed the seasonal Endao River. Southwards the spread of *P. juliflora* next to the road reached 1100 metres south from the seasonal Chemeron River. Although *P. juliflora* was seen growing in dense thickets along the road it was never seen growing in any of the slopes or hills west from the road. From Marigat *P. juliflora* had spread north to the

seasonal Lebus River and south to Perkerra River. Westerly the spread seemed hindered by the slopes and stony terrain, while *P. juliflora* was spreading freely easterly towards the Njemps plains.

P. juliflora was also spreading along the road from Eldume to Lake Bogoria, occasionally forming smaller stands. The southernmost *P. juliflora* was seen close to the shoreline of Lake Bogoria, 4 kilometres south from Loboi. Along the road from Loboi towards Tangulbei, *P. juliflora* had sporadically spread to Sandai, Logumukum, Darajani and Kiserian.

Plant inventories

The number of different species recorded was not differing much between the three sites. In Ng'ambo 18 different species were recorded from 22 quadrates, 16 species in Loruk from 13 quadrates and in Eldume 18 species from 25 quadrates. A total of 31 different plant species was scored from 60 quadrates over all three sites. The species area curves (Figure 15) show the mean of three replications where quadrates were randomly re-sampled and every new species was added to the diagram as they were scored from each quadrate selection. At none of the sites, field sampling was large enough to capture the whole species pool. When re-sampling from the entire dataset of 60 quadrates, the species area curve appears to flatten out above 30 species (Figure 16). When separating quadrates containing *P. juliflora* and quadrates without *P. juliflora* there was however a small difference in the amount of species (Figure 17). The curve showing quadrates without *P. juliflora* had a steeper curve and starts to flatten out at 20 quadrates where it reaches around 22 species. Total amount of quadrates without *P. juliflora* was 39 and the total amount of species 26. The curve representing quadrates with *P. juliflora* reaches 19 species at 21 quadrates, which also were the total numbers. However, the curve with *P. juliflora* showed no tendency to flatten out.

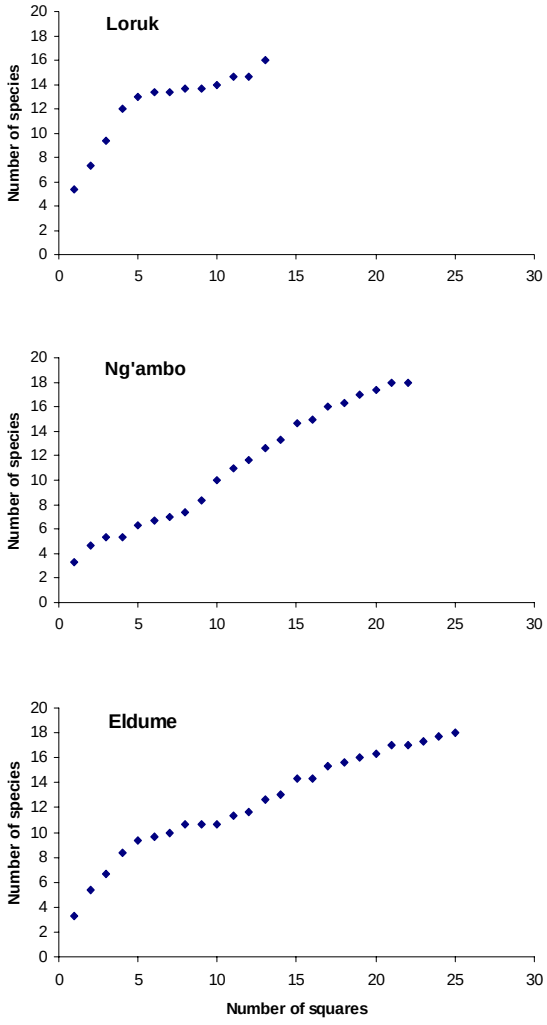


Figure 15. Species area curves from Loruk, Ng'ambo and Eldume

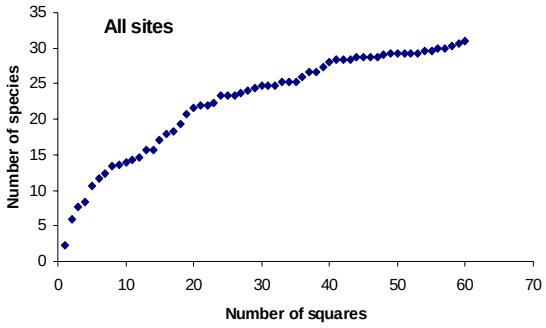
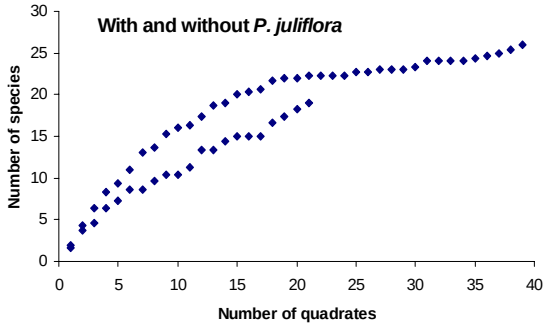


Figure 16. Species area curve from all sites.



Firure 17. Species area curves comparing quadrates with (lower curve) and without *P. juliflora* (upper curve).

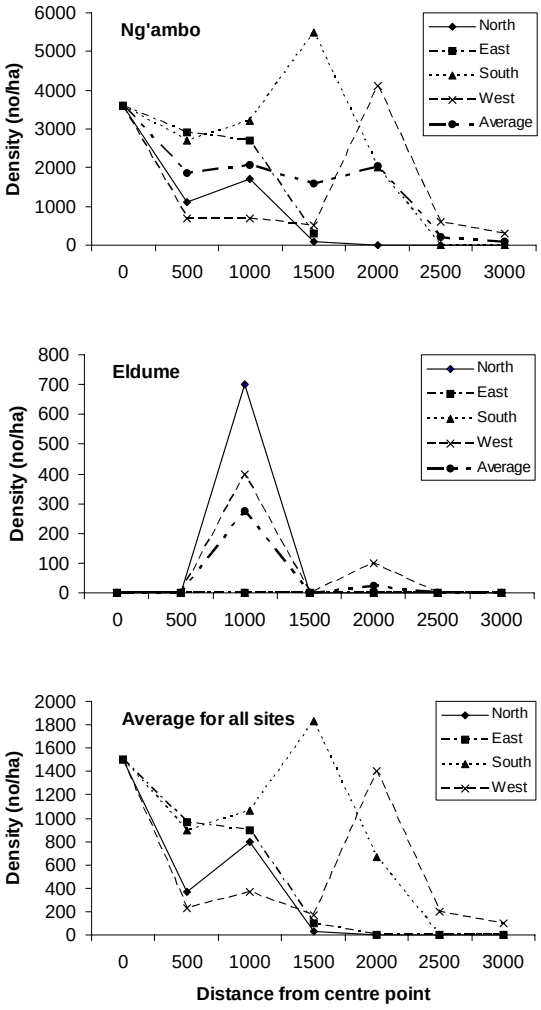


Figure 18. Distribution of *P. juliflora* in different cardinal directions in Ng'ambo, Eldume and average for all sites.

The spread of *P. juliflora* showed different patterns in the three different sites. At Loruk no spread at all was observed, just as expected. In Ng'ambo a trend could be seen with *P. juliflora* decreasing in density as the distance from the centre point of the initial planting site increased (Figure 18). Eldume had a highly patchy distribution of plants in general and *P. juliflora* showed a patchy pattern of spread as well (Figure 18). Since Ng'ambo had the highest density of *P. juliflora*, an average for all sites in different directions was highly influenced by the Ng'ambo population (Figure 18). As an average over all three sites, *P. juliflora* had a decreasing trend in number as the distance from an initial plantation increased (Figure 19).

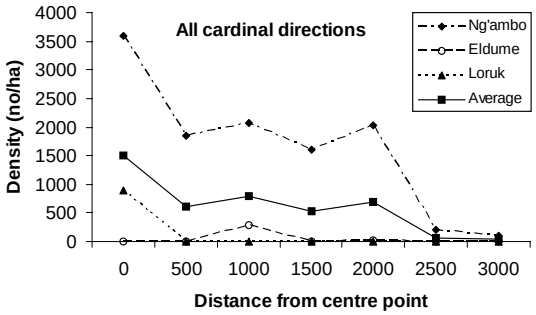


Figure 19. Average distribution for all cardinal directions of *P. juliflora* sites.

Soil samples

The soils from the three sites were slightly different. Exchangeable potassium and pH were higher in the soil from Loruk than Ng'ambo and Eldume, which both had similar levels (Figure 22). Loruk also had the soil with the coarsest texture, followed by Eldume and then Ng'ambo with the finest textured soil (Figure 20).

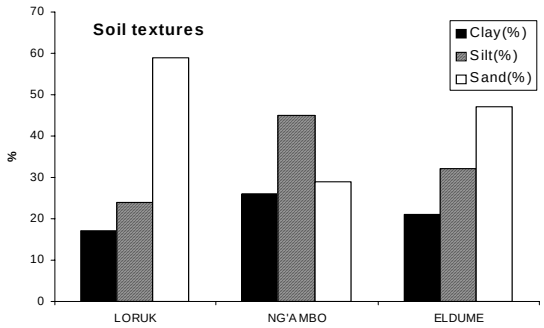


Figure 20. Soil textures in Loruk, Ng'ambo and Eldume.

Furthermore Loruk had the lowest amount of nitrogen and phosphorus while Eldume was intermediate and Ng'ambo had the highest amount of nitrogen of the three sites (Figure 22). The mean amount of soil organic carbon was more or less the same in Loruk and Ng'ambo, while Eldume had less (Figure 22). The soil organic carbon was on average lower in the initial planting sites than in the sites at 500 metres distance from the initial plantations (Figure 21).

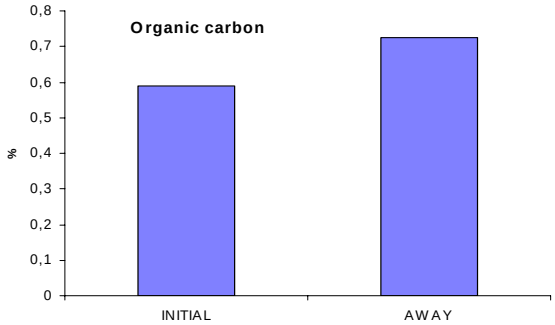


Figure 21. Mean organic soil carbon inside and at 500 m distance from initial *P. juliflora* plantations.

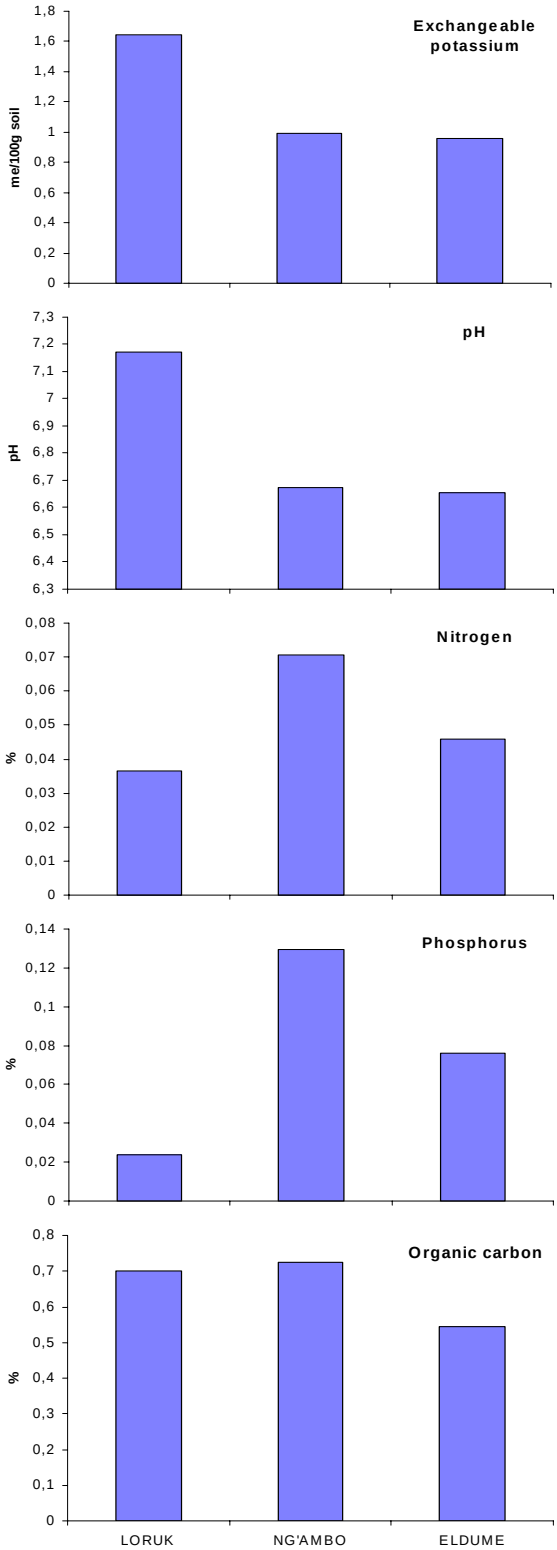


Figure 22. Soil characteristics in Loruk, Ng'ambo and Eldume.

DISCUSSION

The different initial planting sites showed a large variation in the degree of spreading of *P. juliflora*. Furthermore, in some of the sites, *P. juliflora* even seemed to have struggled to survive. This was clearest at Sandai, Logumukum, Loruk and in the area around Kapthurin River. There seemed to be a correlation between the amount of spread and the amount of competing plants. In the sites where nothing else or very little had been growing before the introduction of *P. juliflora*, there was a greater tendency of spreading than in sites where previous vegetation existed. Furthermore, in sites where previous vegetation existed, the soil had in general a more coarse texture, which also might be unfavourable to *P. juliflora*, if the stratum is insufficiently deep (Pasiecznik *et al* 2001, Anonymous 2003). The soils at Loruk are lava soils (Ministry of Agriculture Kenya 1987) and are thus younger than the soils at Ng'ambo and Eldume. That could explain the coarser texture and the higher pH compared to the other two areas and also indicate a higher nutrient status (Malmer pers. comm. 2004).

In general the floral biodiversity of trees and shrubs in the area was very low. The predominant species were *Acacia tortilis, A. mellifera, A. nubica, Acalypha fruticosa, Maerua edulis* and *Lantana camara*. Effects from *P. juliflora* on the floral biodiversity could not be clearly seen in any of the areas. This was because *P. juliflora* had mainly invaded sites where nothing else grew. These conclusions were based on information from the local people who knew what the area looked like before the introduction of *P. juliflora*.

The spread of *P. juliflora* was most severe in Marigat, Ng'ambo, Eldume, Chemeron dam and in water-fed areas such as the Kampi Ya Samaki shoreline. Marigat showed a spread of *P. juliflora* mainly along the roads and houses in Mtego and Marigat Town. Furthermore the spread stretches easterly towards the cultivated areas (Figure 23). In Ng'ambo *P. juliflora* had formed patchy impenetrable thickets and the trees were covering large areas with dense populations (Figure 24). In Eldume an invasion of *P. juliflora* could be seen especially from the western side of the largest plantation (Figure 23). No thickets had formed in the area but the trees seemed to be spreading fast. From Chemeron dam *P. juliflora* had spread a long distance. Local people informed me that seeds were dispersed by goats that were taken to the dam to drink. Spreading from the dam could be traced all the way to Kimorok according to the locals (Figure 25).

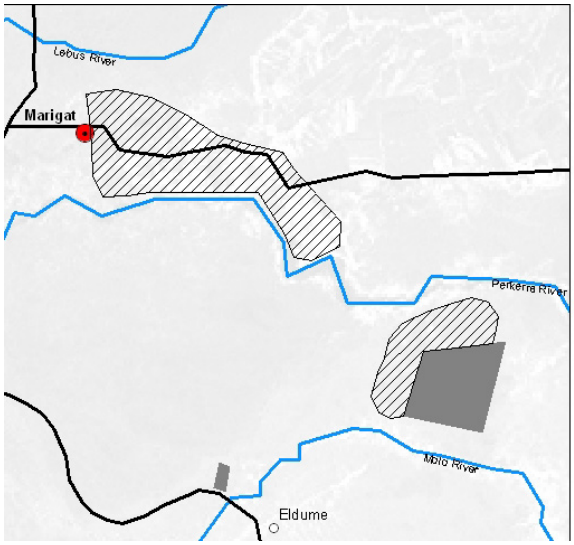


Figure 23. Map showing the pattern of spread in Marigat and Eldume.

P. juliflora seemed to be thriving in water-fed areas. In Kampi Ya Samaki the *P. juliflora* trees had grown dense, even into the water, and hindered people to get in and out with their boats. In the southernmost shoreline of Lake Baringo, *P. juliflora* had started to invade the estuary of Perkerra River (figure 24). The dispersal into this area came probably from Ng'ambo and Salabani.

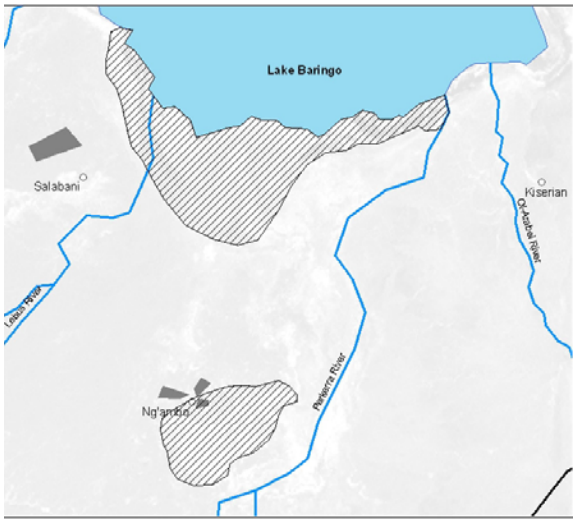


Figure 24. Map showing the pattern of spread in Ng'ambo and southern shoreline of Lake Baringo.

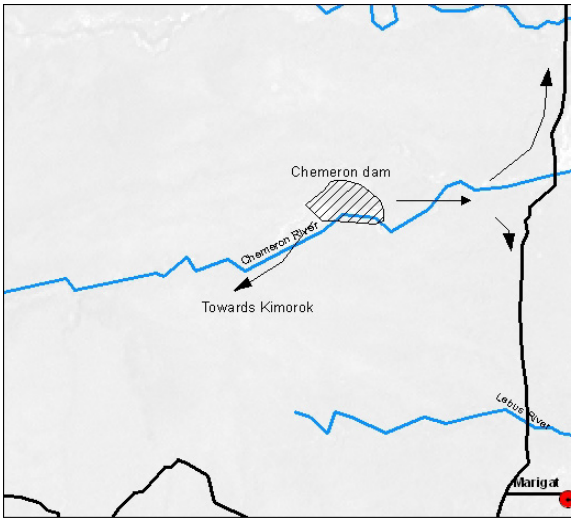


Figure 25. Map showing the pattern of spread around and from Chemeron dam.

A major reason for the spread of *P. juliflora* is that goats eat the palatable mature pods. The presence of animals is usually important for *P. juliflora* to be dispersed over long distances and to germinate (Geesing *et al* 2004). The passage through the digestive tract facilitates germination of the seeds (Shiferaw 2004), which are later deposited with the faeces some distance away from the parent plant. The faeces might also serve as fertilizer to seedlings in an initial stage of establishment (Shiferaw 2004). Another reason for fast spread is that *P. juliflora* produce many and small seeds that can form dormant seed banks. The seeds can then germinate when favourable conditions appear through disturbances such as flooding or rainfall (Pasiecznik 2001, Geesing *et al* 2004, Shiferaw 2004). Water is also an important dispersal agent for *P. juliflora* seeds. Heavy rains in the area make seeds fall from the trees and the following flooding ensure widespread dissemination of the seeds. Since *P. juliflora* has the ability to survive cutting and resprout with fast coppice growth, the species becomes a very strong invader (Shiferaw 2004).

Many studies have shown that *P. juliflora* has an ameliorating effect on soils, which show reductions in soil pH, soil electrical conductivity and soil salinity (Maliwal *et al* 1991, Singh 1995, Bhojvaid *et al* 1996, Bhojvaid & Timmer 1998) and increases in soil organic C, total N, available P and exchangeable K, Ca and Mg (Bhojvaid *et al* 1996, Bhojvaid & Timmer 1998). Improvements have also been shown in soil water movement, moisture holding capacity and hydraulic conductivity due to root penetration in soils planted with *P. juliflora* (Maliwal 1991, Singh 1995, Bhojvaid & Timmer 1998). This suggests that *P.*

juliflora should have a positive effect on the alkaline soils in the study area. It might also improve conditions for crops or other vegetation and some local people had seen such tendencies when planting maize in soils where *P. juliflora* had been removed.

However, other studies have shown allelopathic effects from *P. juliflora*. Nakano *et al* (2003) showed leaching of the allelopathic substance L-tryptophan from the leaves of *P. juliflora*. It has also been suggested that shading from the canopy of *P. juliflora* reduces the understorey biomass (Singh *et al* 1991, Bhojvaid & Timmer 1998). Observations in the study area together with information from local people would support the latter, both in sites with *P. juliflora* and *P. chilensis*. However, it was not clear whether the lack of grass in association with *Prosopis* trees had anything to do with the abundance of goats and cattle in the area. On another note Pasiecznik *et al* (2001) suggests that *P. juliflora* trees, creating shading from the sun and shelter from the wind, have an ameliorating effect on the microclimate under the canopy. Shade and shelter improve water balance by reducing evapotranspiration and increasing relative humidity through reduced wind speed and lowered maximum temperature.

In the nearest future there will probably not be a change in the pace at which *P. juliflora* is spreading. If nothing is done to control *P. juliflora* a gradual acceleration of the spread is most likely to occur. A few initial planting sites, such as the smaller site in Eldume, have just started to spread and an invasion could be expected from them at any time. Areas that seem sensitive to invasion of *P. juliflora* are shaded in Figure 26. This assumption is based on an analysis of a satellite image over the area. The satellite image showed differences in colour for water, vegetation, land types and gradients. Known areas where *P. juliflora* was densely spread were compared on the satellite image with areas not affected by *P. juliflora*. An assessment was then made of the land types where invasion can be expected.

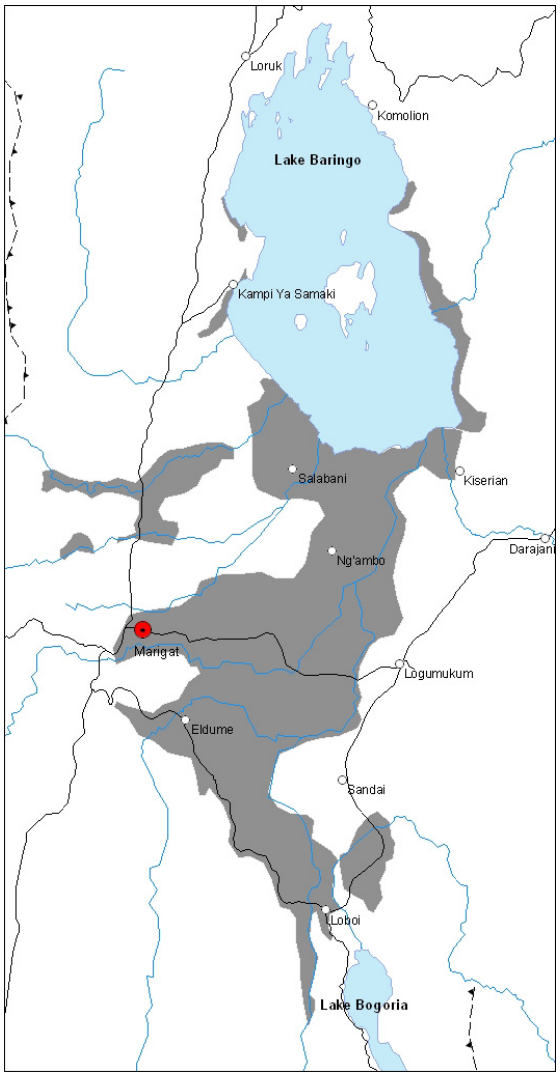


Figure 26. Shaded areas show areas that seem sensitive to invasion by *P. juliflora*.

To eradicate *P. juliflora* completely from the Baringo area would be a long and costly process, due to the ability of the species to resprout after cutting. Studies have shown that to prevent regrowth from *P. juliflora*, the trees have to be cut below ground level (Geesing *et al*. 2004, Shifer-

aw *et al*. 2004). If the people in the Lake Baringo area could utilize *P. juliflora*, the problems with the species would probably be much less. *P. chilensis* was introduced at the same time as *P. juliflora*, but has not become a problem in the same way. The growth form of *P. chilensis* was generally more erect and suitable to constructions and its ability to spread was much less in the study area compared to *P. juliflora*.

In India people are dealing with *P. juliflora* in a different way. There they have learned to utilize it for different purposes such as burning charcoal, building furniture and constructions. The bark can even be used as antiseptic medicine (Sharma 1981). In Niger the view of *P. juliflora* as a threatening weed has now changed and it is seen as a resource. The people have learned a South American technique to process flour from the pods, which is used for human consumption and as coffee substitute (Geesing *et al*. 2004). Examples of other possible uses of *P. juliflora* are fuelwood, timber, chipped wood products, food for livestock, honey, wax, tannins, rope and gum (Sharma 1981, Khanna *et al* 1997, Pasiecznik *et al* 2001).

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Finally I want to dedicate this thesis to my family, for all their support and encouragement.

REFERENCES

Alban L., Matorel M., Romero J., Grados N., Cruz G. & Felker P. 2002. Cloning of elite, multipurpose trees of the *Prosopis juliflora/pallida* complex in Piura, Peru. *Agroforestry Systems*, **54**(3):173-182.

Anonymous. 1987, Fertilizer Use Recommendation Project (Phase I), Final Report, Annex III, Volume 14, Baringo District. *Ministry of Agriculture Nairobi, Kenya.*

Anonymous. 2003. Forestry Compendium. *CAB International Wallingford, UK.*

Batista A.M., Mustafa A.F., McKinnon J.J. & Kermasha S. 2002. In situ ruminal and intestinal nutrient digestibilities of mesquite (*Prosopis juliflora*) pods. *Animal Feed Science and Technology*, **100**(1-2):107-112.

Beentje H. 1994. Kenya trees, shrubs and lianas. *National museums of Kenya Nairobi, Kenya*

Bhojvaid P.P. & Timmer V.R. 1998. Soil dynamics in an age sequence of *Prosopis juliflora* planted for sodic soil restoration in India. *Forest Ecology and Management* **106**(2-3):181-193.

Bhojvaid P.P., Timmer V.R. & Singh G. 1996. Reclaiming sodic soils for wheat Production by *Prosopis juliflora* (Swartz) DC afforestation in India. *Agroforestry Systems*, **34**(2):139-150.

Dulloo M.E, Kell S.P. & Jones C.G. 2002. Conservation of endemic forest species and thethreat of invasive species: Impact and control of invasive alien species on small islands. *International Forestry Review*, **4**(4):277-285.

Ebenshade H.W. & Grainger A. 1980. The Bamburi reclamation project. *International Tree Crops Journal*, **1**:199-202.

Geesing D., Al-Khawlani M. & Abba M.L. 2004. Management of introduced *Prosopis* species: can economic exploitation control an invasive species? *Unasylva,* **55**:36-44.

Groves R.H. 1986. Plant invasions of Australia: An overview. *Ecology of biological invasions*, pp. 137-149.

Hughes C.E. 1994. Risks of species introductions in tropical forestry. *Commonwealth Forestry Review Volume*, **74**(4):243-252.

Hobbs R.J. & Humphries S.E. 1995. An Integrated Approach to the Ecology and Management of Plant Invasions. *Conservation Biology*, **9**(4):761-770.

Kariuki P.M. 1993. A social forestry project in Baringo, Kenya: A critical analysis. *Master of agricultural studies in rural development administration and management thesis*. pp. 41-61.

Kassilly F.N. 2002. Forage quality and camel feeding patterns in Central Baringo, Kenya. *Livestock Production Science*, **78**(2):175-182.

Khanna M., Dwivedi A.K., Singh S. & Soni P.L. 1997. Mesquite Gum (*Prosopis juliflora*):Potential Binder in Tablet Dosage Forms. *Journal of Scientific & Industrial Research*, **56**(6):366-368.

Lenacuru C. I. 2003. Impacts of *Prosopis* species in Baringo District. *Proceedings of workshop on integrated management of* Prosopis *species in Kenya*, pp. 41-47.

Maghembe J.A., Kariuki E.M. & Haller R.D. 1983. Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya. *Agroforestry Systems*, **1**:313-321.

Maliwal G.L., Nadiayadara C.M., Punjani S.H. & Patel C.L. 1991. Changes in soil

properties as influenced by *Prosopis juliflora* and crop covers in salt affected soils. *Annals of Arid Zone* **30**(1):57-60.
Masilamani P. & Vadivelu K.K. 1997. Seed Development and Maturation in Honey Mesquite (*Prosopis juliflora* Swartz. DC.). *Bangladesh Journal of Forest Science*, **26**(1):68-73.
Mathews S. & Brand K. 2004. Africa invaded. The growing danger of invasive alien species. *The Global Invasive Species Programme*. pp. 28-29.
Mooney H.A. & Cleland E.E. 2001. The evolutionary impact of invasive species. *Proceedings of the National Academy of Sciences*, **98**(10):5446-5451.
Nakano H., Nakajima E., Yoshiharu F,. Yamada K., Shigemori H. & Hasegawa K. 2003. Leaching of the allelopathic substance, L-tryptophan from the foliage of mesquite (*Prosopis juliflora* (Sw.) DC.) plants by water spraying. *Plant Growth Regulation*, **40**(1):49-52.
Noad T.C. & Birnie A. 1994. Trees of Kenya. *T.C. Noad & Birnie A. Nairobi, Kenya.*
Oba G, Mengistu Z & Stenseth N.C. 2000. Compensatory growth of the African dwarf Shrub *Indigofera spinosa* following simulated herbivory. *Ecological Applications*, **10**(4):1133-1146
Owen R.B., Renaut R.W., Hover V.C., Ashley G.M. & Muasya A.M. 2004. Swamps, springs and diatoms: wetlands of the semi-arid Bogoria-Baringo Rift, Kenya. *Hydrobiologia*, **518**(1-3):59-78.
Pasiecznik N.M., Felker P., Harris P.J.C., Harsh L.N., Cruz G., Tewari J.C., Cadoret K. & Maldonado L.J. 2001. The *Prosopis juliflora – Prosopis pallida* Complex: A Monograph. *HDRA Coventry, UK.*
Pasiecznik N.M., Harris P.J.C. & Smith S.J. 2004. Identifying Tropical *Prosopis* Species: A Field Guide. *HDRA, Coventry, UK.*
Pimentel D., Lach L., Zuniga R. & Morrison D. 2000. Environmental and economic costs of non-indigenous species in the United States. *BioScience*, **50**(1):53-65.
Sharma I.K. 1981. Ecological and economic importance of *Prosopis juliflora* (Swartz) DC. in the Indian Thar desert. *Journal of Economic and Taxonomic Botany*, **2**:245-248.
Shiferaw H., Teketay D., Nemomissa S. & Assefa F. 2004. Some biological characteristicsthat foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, northeastern Ethiopia. *Journal of arid environments*, **58**(2):135-154.
Singh G. 1995. An agroforestry practice for the development of salt lands using *P. juliflora* and *Leptochloa fusca*. *Agroforestry Systems*, **29**(1):61-75.
Singh G. 1996. Effect of site preparation techniques on *Prosopis juliflora* in an alkali soil. *Forest Ecology and Management*, **80**(1-3):267-278.
Singh G., Gill H.S., Abrol I.P. & Cheema S.S. 1991. Forage yield, mineral composition, nutrient cycling and ameliorating effects of Karnal grass (*Leptochloa fusca*) grown with mesquite (*Prosopis juliflora*) in a highly alkaline soil. *Field Crops Research*, **26**(1):45-55.
Talpada P.M. & Shukla P.C. 1988. Study on Sugar and Amino Acids Composition of *Prosopis juliflora* Pods. *Gujarat Agricultural University Research Journal*, **14**(1):32-35.

Internet

http://www.conference.ifas.ufl.edu/ifsa/posters/Tokida.doc
(*17th symposium of the International Farming Systems Association, 17-20/11/02. Lake Buena Vista, Florida, USA*).

http://www.yourchildlearns.com/africa_map.htm

http://www.michna.com/rae/location_map.htm

Unpublished references

Lepariyo, Kim. 2004. Personal communication. Marigat, Kenya.

Malmer, Anders. 2004. Personal communication. SLU Umeå, Sweden

APPENDIX 1

List of species found during the plant inventories; scientific names and (when available) names in local languages. Plants were identified with help from field assistants who were Ilchamus and Tugen and also from local Pokot-people. Further identification and information about the plants was obtained from the National Museum in Nairobi, Beentje (1994), Noad & Birnie (1994) and from Oba *et al* (2000). Introduced species are marked with (*). Three plants could not be identified by scientific names.

Scientific name	**Ilchamus**	**Tugen**	**Pokot**	**Common**	**Swahili**
Abutilon braunii	Sulubei				
Abutilon fruticosum			Kipkapo		
Acacia albida			Sangak	Apple ring Acacia	
Acacia drepanolobium	Luai	Ngowo	Ayelion	Whistling thorn	
Acacia mellifera	Iti	Ngoror	Talamogh		Kikwata
Acacia nilotica	Ilkioriti	Chebiwo	Kopkwo	Egyptian thorn	Mgunga
Acacia nubica	Ildepe		Pilil		
Acacia tortilis	Iltepes	Sesyet	Ses		Mgunga
Acalypha fruticosa	Lekuru	Loguru	Tapakapon		
Achyrantes aspera	Larupakini			Devil whip	
Balanites aegyptica	Lowwei	Ngoswet	Tuyonwo	Desert date	
Boscia angustifolia	Latacha	Lito	Likwon		
Boscia coriacea	Sorichoi	Sirikwo	Tuywo		Mnafisi
Cadaba farinosa		Birirwet	Arerenyon		Kibilazi-
Cassia occidentalis	Ilkokoi				
Cissus rotundifolia		Cherorowo	Kwarkwarian		
Euphorbia sp.	Kalalia				
Ficus sur/capensis	Ilngaboli			Cape fig	
Grewia tembensis					
Grewia tenax	Ilkogoni	Sitewet	Toronwo		
Indigofera spinosa	Longortomia	Barkelat			
Lantana camara (*)	Ilmagirigiriani	Getipkamoskou			
Maerua crassifolia			Tuwio		
Maerua edulis	Lamalogi	Chebuluswo	Chepuluswo		
Momordica friesorium	Chepkoryon				
Prosopis chilensis (*)					
Prosopis juliflora (*)					
Salvadora persica	Sokotei	Sogotaiwa	Asiokonyon	Tooth brush tree	Mswaki
Solanum incanum	Iltulelei	Lobtwet	Lopotwo	Sodom apple	
Withania somnifera	Lesayiet	Kabarra	Lopotwo		
Ziziphus mauritiana	Ilchokorei Ilbilibili Ilchaniopir Ilmaenyen	Tilolwo	Tlomwo	Jujube	Mkunazi

APPENDIX 2

List showing in what sites different plant species were found. Indications in brackets (X) show that the species were abundant but not scored within quadrates.

Scientific name	**Loruk**	**Ng'ambo**	**Eldume**
Abutilon braunii		**X**	**X**
Abutilon fruticosum	**X**		
Acacia albida	**X**		
Acacia drepanolobium		**X**	
Acacia mellifera	**X**		**X**
Acacia nilotica	**X**	**X**	
Acacia nubica	**X**		**X**
Acacia tortilis	**X**	**X**	**X**
Acalypha fruticosa	**X**	**X**	**X**
Achyrantes aspera		**X**	**X**
Balanites aegyptica		**X**	
Boscia angustifolia		**X**	**X**
Boscia coriacea	**X**		**X**
Cadaba farinosa	**X**		**X**
Cassia occidentalis			(X)
Cissus rotundifolia	**X**	**X**	
Euphorbia sp.		**X**	
Ficus sur/capensis		**X**	
Grewia tembensis			**X**
Grewia tenax	**X**		
Indigofera spinosa		**X**	**X**
Lantana camara		**X**	**X**
Maerua crassifolia	**X**		
Maerua edulis	**X**		**X**
Momordica friesorium	**X**		
Prosopis chilensis		(X)	
Prosopis juliflora	**X**	**X**	**X**
Salvadora persica			(X)
Solanum incanum	**X**	**X**	**X**
Withania somnifera		**X**	
Ziziphus mauritiana		**X**	**X**
lbilibili			**X**
Ilchaniopir			**X**
Ilmaenyen		**X**	

APPENDIX 3

Lab results from the six combined soil samples.

sitename	resid	Clay(%)	Silt(%)	Sand(%)	Total soil phosphorus (%)	Total nitrogen (%)	Exchangeable potassium (me/100g soil)	pH in water	Total soil organic carbon (%)
LORUK	INITIAL	15	25	60	0,025	0,034	1,83	7,88	0,62
LORUK	AWAY	19	23	58	0,023	0,039	1,46	6,46	0,78
NG'AMBO	INITIAL	29	51	20	0,123	0,079	0,74	6,51	0,65
NG'AMBO	AWAY	23	39	38	0,136	0,062	1,25	6,84	0,8
ELDUME	INITIAL	13	17	70	0,045	0,036	1,25	6,75	0,5
ELDUME	AWAY	29	47	24	0,107	0,056	0,66	6,56	0,59

APPENDIX 4

Satellite image over the study area from which maps were made in ArcGIS. White dots indicate waypoints from quadrates where the plant inventories were made.