ENVIRONMENTAL IMPACT ASSESSMENT OF INVASIVE *PROSOPIS JULIFLORA* WEED IN SALABANI LOCATION, MARIGAT DISTRICT, BARINGO COUNTY

EDWARD JUMA MASAKHA

Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Award of the Degree of Master of Science Degree in Environmental Science of Egerton University

EGERTON UNIVERSITY

SEPTEMBER 2013

DECLARATION AND APPROVAL

This thesis is my original work and has not been presented for an award of a degree in any other university

Signature………………………………………… Date…2. 09. 2013………………………………

Edward Juma Masakha

REG.NO. NM12/0633/02

APPROVAL

This thesis has been submitted for examination with our approval as the university supervisors.

Signature ……………………………………… Date …2nd September 2013……………………

Prof. Francis N. Wegulo

Department of Geography

Egerton University

Signature ……………………………………… Date …2nd September 2013……………………

for **Prof. William A. Shivoga**

Department of Environmental Science

Egerton University

2015/104226

ACKNOWELDGEMENT

My special thanks go to Egerton University for giving me an opportunity to pursue Degree course in Masters of Science in Environmental Science. I am indebted to my supervisor Prof. Francis N. Wegulo who spent his invaluable time tirelessly advising, mentoring and guiding this research to a successful completion. I am equally indebted to members of the Faculty of Environmental Science and Resource Development of Egerton University whose inspiration and constructive critic enhanced the perspective and structuring of the thesis. I thank Kenya Forest Research Institute and in particular Messrs. Choge and Luvanda whose sources of data formed the foundation of my studies. I am much indebted to them for allowing me to use their research data. I am also indebted to the Department of Resource Survey and Remote Sensing (DRSRS) for providing me with satellite images which assisted in interpretation of extent of distribution of *P. juliflora* in the study area. Special thanks go to my research assistants Messrs. Harrison Parkolwa and Simeon Kitol for administering the questionnaire in very difficult conditions in Salabani location. Last but not least, I thank all the respondents for sparing their invaluable time to respond to the questionnaires and providing relevant data for this study. Special thanks go to members of Naitonga Farmers Field School (FFS), Government officers and opinion leaders for their insightful information. Finally, I thank the almighty God for seeing me this far.

DEDICATION

To my dear wife Joyce, son Fred and daughters: Tracy, Shanice, Shina and Shaleen who have been inspirational and source of joy to me.

ABSTRACT

Alien invasive species are a threat to functioning and structure of ecosystems in the world; they affect provision of goods and services of ecosystems and have also ecological and socio-economic impacts on ASAL communities. However, they also have economic benefits. This study was therefore designed to determine the environmental and socio-economic impacts of the alien invasive *P. juliflora* species on the communities living in Salabani Location, Marigat District, of Baringo County, in Kenya. The specific objectives of this study were to determine the extent of invasion of *P. juliflora* and its impacts on land use and ecology of Salabani location; secondly the study sort to determine the costs and benefits of *P. juliflora*; and the relationship between soil nutrients and spread of *P. juliflora* in Salabani Location. This study relied on survey research design to collect sample characteristics of 200 households out of the total 2000 households living in Salabani Location. The sample population was determined using the simple random sampling technique. Data was then collected using questionnaires, satellite imagery, and soil sampling. The data was then captured in SPSS programme and analyzed using descriptive and inferential statistics like analysis of variance, Likert score ranking and cost /benefit analysis. The study established that in 1998 *P. juliflora* had only covered 2,906 ha which however, increased at a very fast rate to 8,555ha in the year 2012. The species has significantly reduced other land use patterns like grazing land, acacia woodlots, and forest cover while shrub land increased. Cost /benefit analysis shows that *P. juliflora* is beneficial to the local community as the benefits outweigh the costs. Soil analysis established that *P. juliflora* increased the soil nutrients which might have contributed to its invasive growth. The invasion of *P. juliflora* has out competed native species and changed the structure of the ecology in Salabani location since the weed is allelopathic. *P. juliflora* is now a threat to the ecosystem of Lake Bogoria nature reserve. The plant affects livelihoods of pastoralists as it has replaced acacia woodlots and pasture land. In view of the foregoing findings, the study makes the following recommendations; that the government of Kenya should facilitate the commercial production of charcoal from the plant, encourage and facilitate utilization of other products from the plant like steam energy from the biomass, animal fodder from pods, wax and medicinal value. The study concludes that the dilemma of benefits and costs of *P. juliflora* could be addressed through enhanced sustainable utilization.

TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACRONYMS AND ABBREVIATIONS

ANOVA:	Analysis of Variance
ASALs:	Arid and Semi Arid Lands
CABI:	Commonwealth Agricultural Bureau International
CBA:	Cost Benefit Analysis
CBD:	Convention on Biological Diversity
CBO:	Community Based Organizations
DRSRS:	Department of Resource Surveys and Remote Sensing
EA:	Environmental Audit
EIA:	Environmental Impact Assessment
FAO:	Food Agricultural Organization
FFS:	Farmers Field School
GIS:	Geographic Information System
GISP:	Geographic Information Systems Professional
GOK:	Government of Kenya
ICRAF:	International Council for Research in Agroforestry
IRR:	Internal rate of return
IUCN:	International Union for Conservation of Nature
KEFRI:	Kenya Forestry Research Institute
KEPHIS:	Kenya Plant Health Inspectorate Services
KES:	Kenya shillings
KFS:	Kenya Forest Services
KVDA:	Kerio Valley Development Authority
LULC:	Land Use Land Cover
NEMA:	National Environment Management Authority
NGO:	Non Governmental Organizations
NPK:	Nitrogen Phosphorous Potassium
NPV:	Net Present Value
MEA:	Multilateral Environment Agreements
SPSS:	Statistical Package for Social Sciences
USAID:	United States Agency for International Development
UTM:	Universal Traverse Mercator

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Most modern agriculture, plantation forestry and biodiversity are based on plant species intentionally introduced for various purposes (Richardson *et. al.*, 2000). Thus, thousands of plant species have been and continue to be transported by man to areas far from their natural habitats either for agriculture, forestry or biodiversity conservation. In many parts of the world, some of these alien plant species cause problems as invaders, spreading from sites of introduction and cultivation to invade other ecosystems hence causing concern. Invasive species produce off springs, often in large numbers, that establish at considerable distances far from parent plants. Invasive alien plants can dominate ecosystems and are a growing threat to the delivery of ecosystem services (Van Wilgen *et. al.*, 1998; Levine *et. al.*, 2003). In some cases the same invasive alien species can simultaneously provide benefits and cause negative impacts, hence finding efficient and equitable solutions can be problematic due to conflicts of interest (Sala *et. al.*, 2006; McNeely *et. al.*, 2011). Invasive plant species and woody plants in particular may have major impacts on ecosystem structure and functioning (Versfeld and van Wilgen 2006).

Concern about deforestation, desertification and fuel wood shortages in the late 1970s and early 1980s prompted a wave of projects that introduced *Prosopis. juliflora* and other hardy tree species across the world. *P. juliflora* has survived where other tree species have failed and in many cases become a major nuisance. *P. juliflora* has invaded, and continues to invade, millions of hectares of rangeland in South Africa, East Africa, Australia and coastal Asia (Pasiecznik *et. al.*, 2001). In 2004 it was rated one of the world's top 100 least wanted species (Invasive Species Specialist Group of the IUCN, 2004). In some countries, however, introduced *P. juliflora* has become a highly invasive weed, covering large tracts of land with impenetrable thorny thickets and rendering it unusable. Affected countries have devoted increasing amounts of time and funds to control invasion with limited success.

P. juliflora is an important tree of the ASALs both ecologically and economically. It is extraordinarily drought resistant, and hence it has been found a suitable species for rehabilitation of deserts, saline land, and sand dune stabilization (Geesing *et. al.*, 2010). It is an evergreen tree native to South America, Central America and the Caribbean. In the United

States, it is known as mesquite, in French (*bayarone francais*), in Spanish (*bayatonda blanca*) and in Hindu (*angaraji babul*).

In Kenya, *P. juliflora* is commonly known as 'Mathenge' after the forester working with FAO during its introduction. It is found in most arid and semi-arid lands of Kenya which account for 80% of the country's land area. The common *P. juliflora* found in Kenya is native to South and Central America. It was reported being grown in the 1930s for fodder, shade and as an ornamental plant (Choge *et. al.*, 2007). There was increased planting of *P. juliflora*, to rehabilitate degraded areas and mitigate recurrent famines and massive losses of human and livestock populations due to droughts in the 1970s.

The first records of propagation of *P. juliflora* in Kenya can be traced to tree species trials carried out in 1973 on the Kenyan coast in Mombasa and Menengai in Njoro, Marigat in Baringo, Tana River, and Turkana Districts. Subsequent appraisal of the *P. juliflora* project by the World Bank and FAO led to the formation of Baringo Fuel Wood Afforestation Extension project as a conservation strategy to identify suitable tree species, develop tree planting technologies, and establish tree demonstration plantations at strategic places and extension of tree planting in Marigat Division of Baringo District (Pimentel *et. al.*, 2000). These trials were undertaken to establish the trees and shrubs that were likely to thrive in marginal areas and have the potential to produce fodder or high value cash crops and forage for bees. *P. juliflora* emerged as the most popular species among the local people because of its resilience, drought tolerance, fast growth, and source of fodder for livestock, fuel wood, and rehabilitation of the degraded Marigat rangelands (Meyerhoff, 1991). As the popularity of *P. juliflora* grew, many NGOs, conservation agencies, Government departments, institutions and individuals made seed orders from various sources, both locally and abroad.

The lack of information sharing on the potential dangers of *P. juliflora* and the poor phytosanitary regulations and enforcement policies in the 1960s to 1980s, undesirable *P. juliflora* and its related hybrids were imported into the country. Further planting of the tree was stopped only in the early 1990s when the weedy characteristics of the trees were noticed (Choge *et. al.*, 2002).

Although both *P. pallida* and *P. juliflora* were widely planted from the initial seed orders across the country, these two species have hybridized to the extent that the current varieties have lost most of their valuable woody attributes and have become very invasive. Livestock and wild animals eat the pods, leaving undigested seeds in their fecal matter wherever they graze, whereas pods are washed downstream by floodwaters and rivers. The combined lack of knowledge on how best to manage and use these trees and their presence on communal lands where people have little or no responsibility to control its spread, have helped this rather invasive *P. juliflora* species to get a foothold and invade (Choge, 2007). The impact of the weed on the environment and livelihoods of pastoralists is considered as a national disaster. Pastoralists, whose livelihoods are mainly centered around livestock, and least on tree products, inhabit most of the areas where *P. juliflora* occurs. In 2007, the affected communities in Marigat instituted a court case against the State for sanctioning the introduction of this 'dryland demon'. The Government was directed by the High Court to clear the weed and compensate the local people. To date the directive has not been implemented to date. Also animal feed manufacturers petitioned the government to put on hold biological control as they test viability of the tree pods for animal fodder production (Choge, 2007).

1.2 Statement of the problem

Since its introduction in 1980s, *P. juliflora* has spread outside areas where it was originally planted in Marigat Division, causing a number of social, ecological and economic concerns. It is a formidable invader affecting land use like forests, acacia woodlots and pastureland. Although considered a suitable multipurpose tree (Pasiecznik *et. al.*, 2003), it has affected the livelihoods of the nomadic pastoralists and agriculturalists alike. This is thought to contribute to social economic hardships. This has placed constraints on sustainable development, economic growth, poverty alleviation and food security as envisaged in Kenya's Vision 2030. However, no sufficient research has been done on the land use/land cover changes caused by the plant, the distribution and the impacts of the plant on the socioeconomic welfare of the respondents .It is therefore the intention of this research to establish the extend of invasion of the plant in the study area, its impacts on the environment, land use, soil nutrients and economic benefits and loses to the respondents.

1.3 Objectives of the study

1.3.1 Broad objective

The broad objective of this study was to provide a clear understanding of the environmental and socioeconomic impacts of *P. juliflora,* an invasive weed species on the people of Salabani Location in Marigat District of Baringo County.

1.3.2 Specific objectives

Based on the above broad objective, this study sought to pursue the following three specific objectives:

1. To determine the extent of invasion of *P. juliflora* and the impacts on land use and ecology of Salabani.
2. To determine the costs and benefits of *P. juliflora* in Salabani Location.
3. To determine relationship between soil characteristics and the spread of *P. juliflora* in Salabani Location.

1.4 Research questions

The following questions were pursued to address the three specific objectives.

1. To what extent has invasion of *P. juliflora* spread and what are the impacts on land use and ecology of Salabani Location?
2. What are the costs and benefits of *P. juliflora* in Salabani Location?
3. What is the relationship between soil characteristics and the spread of *P. juliflora* in Salabani Location?

1.5 Justification of the study

P. juliflora has invaded the study area and its impacts are both beneficial and a cost to the livelihoods of the respondents. This spread has become a concern to respondents and environmentalists alike. This study seeks to determine extent of invasion of the weed and the resultant socioeconomic and ecological impacts. The study will assess the costs and benefits of the plant and resultant impacts on land use. This is important as it will help the respondents realize the economic potential of the plant. The study will also help policy makers and extension workers to advice on best alternative uses of the weed based on a cost benefit analysis. This will contribute to sustainable development as envisaged in Kenya's Vision 2030 strategy. The study will open opportunities to private sector investors interested in the commercial potential of *P. juliflora* like charcoal, bio-fuel, and animal fodder. The knowledge about the spread and distribution of the plant, the positive and negative impacts and potential uses of the plant will help government in decision making process on best alternative options to manage *P. juliflora*.

1.6 Definition of terms

Allelopathy This is plant to plant interference caused by hormones released by plants that influence oxidative stress due to phytohormones and abscisic acid to suppress growth of neighbouring plants like 5-hydroxy juglone and ethylene as secondary oxidates.

Alien plants Plant taxa whose occurrence in a given area results from their introduction (intentionally or accidentally) by human activity (synonyms: "exotic plants," "nonnative plants," "non indigenous plants").

Alien species: Any exotic non-indigenous life form originating from outside a given ecological location.

Aquifer A geological formation containing sufficient saturated permeable material to yield significant quantities of water.

Biodiversity Variability among living organisms including the ecological complexes of which they are apart and the diversity within and among species and ecosystems

Bio-invasion This term is used synonymously as biotic invasion, which refers to the invasion of any species of fauna or flora.

Casual plants Alien plants that may flourish in an area but do not persist for more than one life cycle without further introductions (includes taxa labeled in the literature as "waifs," "occasional escapes," and "persisting after cultivation").

Ecological impacts Changes in species composition, structure and functioning of an ecosystem due to invasion of *P. juliflora.*

Ecology The study of interactions among and between organisms and their environment such as interaction between organisms and their abiotic environment

Ecosystem A community of living organisms (biotic component) in conjunction with the non living components of their environment like air, water and soil (abiotic component) all interacting as a system.

Endemic species Species of fauna and flora restricted to a particular geographical region.

Environmental Impact Assessment: A systematic scientific assessment of impacts of any development project or proposal on components of the environment which includes socioeconomic and ecological impacts to both biotic and abiotic components and can be both positive and negative in nature.

Invasive plants Alien plants that recruit reproductive offspring, often in very large numbers, at considerable distances from parent plants and thus have the potential to spread rapidly.

Invasive species Species which out-compete native species once introduced in a new ecological zone.

Naturalized plants Alien plants that reproduce and sustain populations over more than one life cycle without direct intervention by humans (or despite human intervention); they often recruit offspring freely, but often just near adult plants, and do not necessarily invade natural, semi-natural, or human made ecosystems.

Obnoxious weed Refers to any invasive species choking the original or native species in a given area.

Ramsar site Wetlands of international importance in conservation of water fowl species according to the Ramsar Convention of 1971

Riparian habitat: Dynamic complex of fauna and flora and their non- living environments adjacent to watercourses.

Transformer spp: A subset of invasive plants that change the character, condition, form, or nature of ecosystems over a substantial area relative to the extent of that ecosystem.

Sustainable development: Development that meets the needs of the present generation without compromising the ability of future generations to meet their needs by maintaining the carrying capacity of the supporting ecosystems.

Weeds: Plants (not necessarily alien) that are undesirable from a human point of view. These are usually taxa with detectable economic or environmental effects (synonyms: "pests," "harmful species," "problem plants"). Environmental weeds are alien plant taxa that invade natural vegetation, usually adversely affecting native biodiversity or ecosystem functioning.

Wetlands: An area where fauna and flora have become adapted to temporary or permanent flooding by saline brackish or fresh water to not more than 3 metres.

1.7 Scope of the study

This study assessed the impacts of *P. juliflora* an invasive weed species on land use and socioeconomic being of the people of Salabani location in Marigat District, Baringo County. The study examined changes in land use from 1998 to 2012 by comparing acreages under pastureland, agriculture, forests, settlement, acacia woodlots and shrub land using satellite images. Ecological impacts examined were changes in species composition, structure and functioning of ecosystems. The study established the emergence and disappearance of plant species due to invasion of the alien weed which is known to be allelopathic. The study mainly focused on Salabani location due to the wide geographical distribution of the weed in this part of Marigat District. The study conducted surveys using a questionnaire on a randomly selected sample population of 200 households. Focused group discussions were also conducted for key informants. Soil samples were collected for nutrient analysis to determine any relationship between soil nutrients and spread of *P. juliflora*.

1.8 Assumptions of the study.

This study was guided by the assumption that all respondents were honest in providing information relating to impacts of *P. juliflora* on their livelihoods. Secondly that most of the observed impacts on land use and ecology were as a result of the invasion of *P. juliflora* and not climate change.

1.9 Limitations of the study

The main challenge of this study was inaccessibility to households for purposes of gathering data because of thorny thickets of *P. juliflora* and floods. Some respondents had reservations on any benefits accruing from *P. juliflora* and were unwilling to freely answer the relevant questions as presented to them. The researcher had to spend time assuring them of confidentiality of their views with assistance of local leaders and research assistants. Some environmental costs and benefits were difficult to quantify in monetary terms as they are intangible like aesthetics and controlled dust pollution hence were not included in the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is concerned with review of literature related to alien and invasive species especially *P. juliflora*, their occurrence, impacts and management locally and globally. It also includes opinions related to the planned research.

2.2 Occurrence of invasive weeds in the environment

Alien species are non-native or exotic organisms that occur outside their adaptive and dispersal ranges (Raghubanshi *et. al*., 2005; Haysom and Murphy, 2003). The International Union of Conservation of Nature (IUCN) defines alien invasive species as species which become established in natural or semi natural ecosystems or habitats, an agent of change, that threatens native biological diversity. Invasive alien species are species introduced deliberately or unintentionally outside their natural habitat, where they establish, invade, out-compete native species and take over the new environment. They are widely distributed in all kinds of ecosystems throughout the world (Convention on Biological Diversity (CBD, 2001).

Plants, mammals and insects comprise the most common types of invasive alien species in terrestrial environments (Raghubanshi *et. al*., 2005). Invasive species have overtime affected every ecosystem type on the planet, and are now considered as the second greatest global threat to biodiversity, after habitat destruction (Raghubanshi *et. al*., 2005, Essa *et.al*., 2006). Moreover, factors of climate change such as global warming trigger suppression of native biodiversity by invasive alien species (Kathiresan, 2008). Invasive species impact on native species directly competing for resources such as food, water and breeding sites as well as indirectly by altering habitats. They also modify hydrology, nutrient cycling and other ecosystem processes. These impacts dramatically change the ecosystem both positively and negatively (Pasiecznik *et. al*., 2001; Shackleton *et. al*., 2006).

Threats to biodiversity and habitat destructions are interacting phenomena: habitat destruction can make areas more vulnerable to invasive species, and species invasions can result in the destruction of habitats (Raghubanshi *et.al*., 2005). Apart from their threat to biodiversity and ecosystem services, invasive species have significant social, ecological and economical impacts. They reduce agricultural yields, grazing areas, water availability, and contribute to spread of vector born diseases. Invasive alien species can be integrated into the livelihoods of the local people in a number of ways (Shackleton *et.al.* 2006). The first means is when the local community introduces or accepts the introduction of alien species for their clear use. Negative consequences may arise as these newly introduced species spread to a wider landscape away from the control of the local community and natural predators (Shackleton *et.al.*, 2006).

Secondly the invasive alien species are intentionally introduced into an area and subsequently escape, or they spread into surrounding areas. The escaped population may not be widely used initially but when the number of indigenous species becomes scarce, the local community starts to utilize the newly introduced species. Thirdly, local people might simply use invasive alien species because they have resigned themselves to their presence like use of *P. juliflora* for fuel wood and fencing in Salabani (Shackleton *et.al.* 2006).

The last situation is where people learn to live with invasive alien species that have no obvious use. In the early stages of invasion the species may pose relatively little threat or inconvenience. When the density and extent of invasion increases, it impacts on other ecosystem goods and services. But the rural poor may lack both knowledge and capital to control or eradicate them. In such circumstances the livelihood of the poor is undermined. In all these situations, local communities have to consider the positive and negative impacts through the use of invasive alien species. The net trade-offs will be positive or negative depending on a number of factors such as the extent and density of invasion, availability of alternatives, cost and mechanism of control, current vulnerability, and severity of loss of ecosystem (Shackleton *et.al.*, 2006).

Differences between native and exotic plant species requirements and modes of resource acquisition and consumption may cause a change in soil structure, its profile, decomposition, nutrient content of soil, and moisture availability. Invasive species are thus a serious hindrance to conservation and sustainable use of biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems (Raghubanshi *et.al.*, 2005). Biological invasions now operate on a global scale and will undergo rapid increase in this century due to interaction with other changes such as increasing globalization of markets, rise in global trade, travel and tourism. Furthermore, it is anticipated that the problem will be exacerbated in the future by climate change, which is likely to favour species that are opportunistic (Pasiecznik *et.al.* 2001).

Alien invasive species have unique characteristics over the native ones (Raghubanshi *et.al.*, 2005). They do not need special environmental requirements for seed germination, have rapid seedling growth and produce seeds for longer period of time as long as environmental condition permit, they are also highly tolerant to climatic and edaphic variations and have an ability to compete and drive off other species from their habitat.

Moreover, they can reproduce sexually and asexually (Sharifi *et.al.* (2008), Forest invasive species can negatively affect forest ecosystems or damage specific forest products. *P. juliflora*, like any invasive species, is invasive only under conditions that are favorable to their spread (Geesing *et.al.* 2004). The ecological adaptation of invasive plant species to the harsh conditions of the dry land is indicated by deep root system (Pasiecznik *et.al.* 2001), few stomata to reduce water loss (Nilson *et.al.*, 1983), slow growth rate during the dry season (Sharifi *et.al.* 2008).

High alkaline soils are a major constraint for successful growth of most plants. However, *P. juliflora* can tolerate high saline and alkaline soils, very poor physiochemical and biological conditions of the soils. Hence *P. juliflora* can predominantly grow in arid and semi arid regions of the tropics (Pasiecznik *et.al.* 2001). The plant can even survive and grow with salinity levels equal to that of the sea water (Felker *et. al.*, 2007). The recent global assessment and global data sets showed that there are 1348 serious agricultural weed species worldwide. Invasive alien species have affected 30% of threatened birds, 11% of threatened amphibians, 8% of threatened mammals and 15% of threatened plant (Daechler, 1998). In 2004, IUCN identified 81 Invasive Alien Species (IAS) in South Africa, 49 in Mauritius, 44 in Swaziland, 37 in Algeria and Madagascar, 37 in Kenya, 28 in Egypt, 26 in Ghana and Zimbabwe, and 22 in Ethiopia.

P. juliflora has survived where other tree species have failed, and in many cases, have become a major nuisance and cause for land cover changes. *P. juliflora* has invaded, and continues to invade, millions of hectares of rangeland in South Africa, East Africa, Australia and coastal Asia (Pasiecznik *et.al.* 2001). *P. juliflora* had until 2000 been proclaimed weedy in its native ranges, and as an alien invasive species in Australia, Caribbean, Eritrea, India, Iraq, Pakistan, south Africa, Sudan and the western Africa islands. As a result *P. juliflora* is known to be invasive all over the arid and semi-arid lands, where they drastically reduce the cover of forage plants and threaten crop cultivation and grazing lands (Laxen, 2007).

P. juliflora and closely related species have been widely used in dry lands to halt desertification because they tolerate low rainfall, great heat, poor and saline soils and their ability to stabilize sand dunes. Other products include good-quality fuel wood and charcoal, pods as fodder and food, and seed gum. Because of the low palatability of its foliage, *P. juliflora* is suitable for use as a live fence (CABI, 2000). It has been widely introduced throughout the dry tropics and has spread over large tracts of Africa, Asia, and South America (Jadhav *et.al.*, 1993; Sharma and Dakshini, 1998; Tewari, 1998; Coppen, 1995; El Fadl, 1997). These authors also argued that the spread of *P. juliflora* must be checked in areas that are not degraded and suggested that this could be achieved through proper management but did not provide concrete guidelines.

Although the deleterious impacts of root competition and allelopathy of *P. juliflora* in agricultural areas have been noted earlier (Baumer, 1990), the environmental and human impacts of invasions by this species have only recently gained more attention (Pasiecznik *et.al.* 2001). In northeastern Brazil, *P. juliflora* has spread from managed agricultural systems into arid shrub lands rich in endemic species, where its impact on biodiversity is viewed as highly detrimental (Hulme, 2012). In Gujarat, India, *P. juliflora* is perceived to negatively affect pastures, cattle health, and water resources (Jhala, 1993). However, it does play a role in erosion control and provides people with a source of income from some of its products such as charcoal, pods, and honey. It is therefore thought that the tree should be contained rather than eradicated (Tiwari and Rahmani, 1999). In a study in India, the weed was found to colonize agricultural land and difficult to remove, its thorns caused infections and punctured bicycle tyres, the leaves are unappealing to goats and no grass or crops could grow in its shade. Consequently, local people considered *P. juliflora* useless (Gold, 1999).

The genus *Prosopis* has an interesting history in South Africa. Several species have been widely used as amenity trees, mainly for livestock fodder and shade, in the arid parts of the country. After the spontaneous hybridization of several taxa, (*P. glandulosa* var. *torreyana* and *P. velutina*), *Prosopis* spp rapidly spread over huge areas, making large tracts of rangeland unproductive (Harding and Bate, 1991). In Australia, *P. juliflora* has covered over 800,000 ha, mainly in northern Australia causing serious impacts (Pasiecznik *et.al.* 2001).

2.2.1 *P. juliflora* as an alien invader

Invading *P. juliflora* tends to form dense, impenetrable thickets, associated with unfavorable impacts on human economic activities. Millions of hectares of rangelands have already been invaded in South Africa, Australia and coastal Asia (Pasiecznik, 2001). In northern Sudan the Gash Delta on Atbara River has almost been completely taken over by *P. juliflora* (Catterson, 2003). In the Awash basin of Ethiopia, the plant has invaded pastoral rangelands in Awash Valley, and Eastern Harerge. It is one of the three top priority invasive species in Ethiopia and has been declared a noxious weed (Pasiecznik, 2001).

Key factors thought to influence invasion of *P. juliflora* are land use changes, competitive ecological advantages, and climate change (Pasiecznik *et.al.* 2001). In Australia and South Africa, for instance, *P. juliflora* invasions followed periods of high rainfall when conditions for germination and establishment were particularly favourable. In northern India, *P. juliflora* is a pioneer species that rapidly colonizes denuded/abandoned ravines. Invasions into riverine areas and degraded rangelands of Africa, Asia and Australia have resulted in high density populations. Whatever the trigger for invasion, the principal factor in this process is the rapid and prolific seeding of mature *P. juliflora* (Zimmerman, 1991). Seed production is estimated at 630,000 to 980,000 seeds per mature tree per year (Harding, 1988). Those seeds are most likely to germinate when the sugary pods are consumed by livestock, the seeds scoured while passing through the animals' digestive tract, and the scoured seeds dropped into moist manure (Felker, 2003).

In Sudan, *P. juliflora* is reported to depress the growth and survival of indigenous vegetation around it. Some farmers in Kassala region claim to have lost their farmlands to *P. juliflora*. El Fadl (1997). They further claim that it is costly to clear, it causes destruction to agricultural crops, and its thorns are harmful both to farm workers and machinery. It is claimed to consume underground water, threatening the Beisha oasis in western Sudan (Laxen, 2007). In Ethiopia, the aggressive invasion in pastoral areas is displacing native trees, forming impenetrable thickets and reducing grazing land. Agricultural lands and protected areas such as the Awash National Park are threatened (Pasiecznik, 2001). In South Africa, it is estimated that *P. juliflora* reduces mean annual run off by about 481 million cubic meters across the country. For over fifty years, ranchers in south-western USA and Argentina tried a range of techniques to eradicate or control *P. juliflora* (Pasiecznik, 2001). South Africa and Australia are experimenting with biological control methods, using seed-eating beetles. Because eradication efforts have been neither cost-effective nor technically successful, it seems the best option might be to adapt suitable land use options. Reduction in stocking rates can encourage good grass cover, which may prevent seedling establishment. Existing dense stands may be thinned and/or pruned, cut stumps treated, fuel wood, charcoal and timber products harvested from existing stands (Pasiecznik, 2001).

2.2.2 Introduction of *P. juliflora* into Africa

The native range of the *P. juliflora-pallida* complex covers a broad geographical region in the Americas, from latitudes 22-25 degrees north to 18-20 degrees south. Countries in this range include Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Ecuador, Peru and the Caribbean and Galapagos islands

(Pasiecznik *et.al.*, 2001). In Africa, *P. juliflora* was introduced in 25 countries spanning all regions of the continent, including Morocco, Algeria, Tunisia, Libya, Egypt in North Africa, Cape Verde, Senegal, Gambia, Mauritania, Mali, Burkina Faso, Niger, and Chad in the Sahel region of Western Africa, Ghana and Guinea-Bissau and Nigeria in West Africa, Sudan, Ethiopia, Eritrea, Kenya, Tanzania in the East and Horn of Africa, and in Namibia, Zimbabwe, South Africa and Reunion in Southern Africa (Pasiecznik *et.al.,* 2001). Earliest documented introductions of *P. juliflora to* Africa are Senegal (1822) South Africa (1880) and Egypt (1900). Subsequent introductions to other African countries remain unclear (Zimmerman, 1991: Pasiecznik *et.al.*, 2001*)*. Unfortunately, the introductions into Sahelian Africa and the Indian subcontinent were from trees with non-palatable pods (Alban *et.al.* 2002). In East Africa in particular, the exact origins of *P. juliflora* remain uncertain. *P. juliflora* may have come in via livestock from Sudan, southern Africa or by traders from India or southern Africa.

In Kenya *P. juliflora* was intentionally introduced by the Kenya Government as a strategy to rehabilitate the ASAL areas following the severe droughts and land degradation during the 1970s (Sumanen, 1983). There was subsequent appraisal of the *P. juliflora* project by the World Bank and FAO which led to the formation of Baringo Fuel Wood Afforestation and Extension project as a conservation strategy to identify suitable tree species to plant in the ASALS of Kenya. The other objective of this project was to develop tree planting technologies, establish tree demonstration plantations at strategic places and extension of tree planting in Marigat Division of Baringo District (Sumanen, 1983). These trials were undertaken to establish the trees and shrubs that were likely to thrive in marginal areas and have the potential to produce honey, fodder or high value cash crops.

The first records of propagation of *P. juliflora* in Kenya can therefore be traced to these trials carried out in 1973 in Bamburi of Mombasa District, Menengai in Nakuru District, Marigat in Baringo District, Bura in Tana River District, and on the shores of Lake Turkana in Turkana District. *P. juliflora* emerged as the most popular species among the local people because of its resilience and fast growth. It was also preferred as a source of fodder for livestock, fuel wood, and rehabilitation of the degraded Marigat rangelands (Meyerhoff, 1991). As the popularity of *P. juliflora* grew, many NGOs, conservation agencies, Government departments, institutions and individuals made seed orders from various sources, both locally and abroad. The lack of information sharing on the potential dangers of *P. juliflora* and the poor phytosanitary regulations and enforcement policies in the 1960s to 1980s led to the passage of undesirable *P. juliflora* and its related hybrids into the country.

Further plantings stopped only in early 1990s when the weedy characteristics of the trees were noticed (Choge *et.al.* 2002).

Although both *P. pallida* and *P. juliflora* were widely planted from the initial seed orders across the country, these two species have hybridized to the extent that the current varieties have lost most of their valuable woody attributes and have become very invasive (Choge *et. al.*, 2002). Livestock and wild animals eat the pods, leaving seeds wherever they go, and pods are also taken downstream by rivers and floodwaters. The combined lack of local knowledge on how people could best manage and use these trees, and their presence on communal lands where people have little or no responsibility to control its spread, have helped this rather invasive *P. juliflora* to first get a foothold, and then invade. The *P. juliflora* invasion has had a dramatic impact on the environment and livelihoods of pastoral communities. Pastoralists, whose livelihoods are centered around livestock, and least on tree products, inhabit most of the areas where *P. juliflora* occurs.

The initial seeds for *P. juliflora* were sourced from Brazil and Hawaii (Choge *et.al.* 2002). The species were introduced with the intention of ensuring self-sufficiency in wood products, making the environment habitable and safeguarding the existing natural vegetation from overexploitation by the rising human populations. These introductions were uncoordinated and seeds sourced from commercial suppliers without reference to origin or quality. A report by the Kenya Forestry Research Institute and Forestry Department (Choge *et.al.* 2002) shows pockets of large-scale colonization across the semi-arid areas of Kenya, with large-scale invasions indicated in the Tana River delta, and around the shores of Lake Turkana.

Other authors claim that *P. juliflora* was introduced in Kenya from Australia and South America. However *P. alba, P. pubenscenes, P. tamarugo* failed to establish at nursery stage in Marigat (Meyerhoff, 1991). However, Ndegwa (2006) noted that *P. juliflora* was introduced in Bura in 1983 with provenances from Holland. *P. juliflora* emerged as the most popular species among the local people because of its resilience.

2.2.3 Factors shaping perceptions of alien invasive species

Peoples' perceptions of invasive species depend on whether their economic needs are met by the species. (Pasiecznik *et.al.* 2001) In the Indian province of Rajasthan, local peoples' perceptions of *P. juliflora* were favorable during the early stages of its introduction. At that time, it was welcome as a field boundary marker and indeed helped to avert a significant fuel wood shortage. Peoples' perceptions changed later as the negative effects of the invasion of agricultural land, its sharp thorns, suppression of grasses and crops became more pronounced. Income levels and dominant livelihood strategies are also important determinants of how individuals perceive invasive species (Pasiecznik *et.al.* 2001).

In India, the more affluent who can afford cooking gas perceive *P. juliflora* negatively, while the rural poor who cannot afford cooking gas value the plant as a source of fuelwood. Similarly, ranchers and pastoralists whose main livelihood strategy depends on livestock keeping perceive the plant negatively as it invades there valuable pastureland (Tewari *et.al.* 2000).

Other factors that influence peoples' perceptions of invasive species include impacts on property and natural ecosystems, ornamental value, opinion leaders, views in the media and the costs of managing the species (Veitch and Clout, 2001). It seems that peoples' perceptions are fundamentally shaped by the way their daily lives interface with the species and how it affects their livelihoods and local economies. An economically beneficial species will more likely be favored in as far as the costs of managing it do not exceed the discernible benefits. However, calculations of benefits and costs will vary across a population. The livelihoods strategies that individuals pursue, their wealth levels and their gender are central factors shaping how they relate and value invasive species (Veitch and Clout, 2001).

While an understanding of perceptions may provide valuable insights into individual and group valuation of invasive species, it however provides no indication of how these valuations motivate some form of action response (Nabli and Nugent, 1989). They may be formal such as markets or informal such as cultural norms and conventions.

At the individual level, it is generally recognized in Harding's concept of the Tragedy of the Commons that private property rights serve to create substantial incentives for investment in resource management. Under this institutional arrangement, individuals who invest their time, effort and money are able to reap benefits of their investment for themselves. Following this argument, individual owners of property will be more likely to engage in *P. juliflora* management activities because they will be assured of benefits from their investments. However, accounts of invasive species management elsewhere in the world suggest that private property rights may be neither necessary nor sufficient to check the spread of invasive species (Pasiecznik *et.al.* 2001). Although the United States has a well-developed system of private property rights for land ownership, the spread of invasive species across property boundaries continues to be a major concern (Perrings *et.al.*, 2002).

In situations where individual actions are interdependent and related such as in the use of commonly held resources, incentive structures are even less likely to lead to efficient outcomes. Each of these individuals will want to overuse the resource, leading eventually to its depletion or degradation (Perrings *et.al.* 2002). Theories of collective action provide insights into what motivates individuals to coordinate their activities to solve collective problems.

Government policies can also shape responses to invasive species. The policies may create incentives or disincentives that affect how people utilize invasive species and the extent of utilization (Perrings *et.al.* 2002). Government tree planting schemes, such as those common in the late 1970s and early 1980s in Kenya created incentives that did not consider the possible costs that *P. juliflora* later imposed on society. Similarly, government policy may constrain the range of possible profitable uses of invasive species. For example in Kenya, restrictions on charcoal transportation and sale in early 2000 may have discouraged more intense and profitable utilization of *P. juliflora*, which could have effectively contributed to its rapid spread (Choge *et.al.* 2007).

2.3 Characteristics that make *P. juliflora* a formidable invader

In recent decades *P. juliflora* has attracted much attention because of its ability to survive in extremely arid, saline and inhospitable conditions. The plant is known to tolerate very high salinity levels upto that of the sea water (Felker *et.al.* 2007). The combination of its long life cycle, ability to survive droughts, high seed production and dormancy of seeds make *P. juliflora* an extremely resilient invader which can quickly take advantage of suitable environment and dominate entire ecosystems (Chamberlain and Pottinger, 2006). *P. juliflora* has many biological characteristics that promote its invasion of new areas. It starts fruiting as early as 3- 4 years old. One mature tree can produce between 630,000 to 980,000 seeds per annum (Harding et.al., 1988). *P. juliflora* is a prolific seed producer. Seeds from the plant are covered by hard seed coat capable of surviving for a very long period of time (Pasiecznik *et.al.*, 2001). The plant produces a mixture of seeds; few of them germinate immediately after dispersal and majority remain dormant for even ten years for future germination. The pods are fleshy and sweet which attracts domestic and wild animals. These animals feed on the pods and disperse the undigested seeds in their nutrient rich fecal matter (Felker 2003). Moreover, when the stands are cleared, seeds accumulated in the soil start to germinate and regenerate again. It reproduces both sexually from seeds and asexually through coppicing from cut stems and roots. In addition to these characteristics, *P. juliflora* is known to have allelopathic chemicals that inhibit the germination and spread of other plant species (Baumer, 1990; Coppen 1995; Burkart, 2007). This mechanism, combined with drought condition can inhibit other species and eliminate any kind of competition. It has a deep rooting system and stout tap root which can even reach upto 20 metres deep in such of water in desert conditions (Pasiecznik *et.al.* 2001). Their leaves have few stomata which reduce water loss during droughts (Nilsen *et.al.,* 1983) and the plant slows down its growth rate during dry seasons (Sharifi *et.al,* 2008).

2.4 Socio-economic importance of *P. juliflora*

P. juliflora plays a leading role in the afforestation of arid and semiarid lands. It fits very well into dryland agroforestry systems, controlling soil erosion, stabilizing sand dunes, improving soil fertility, reducing soil salinity, providing fuelwood, supplying feed and forage for grazing animals, furnishing construction timber and furniture wood, supplementing food for humans, and promoting honey production (Pasiecznik *et.al.* 2001).

P. juliflora produces good quality fuel of high calorific value, which burns well even when freshly cut. It also produces high quality charcoal and its heartwood is strong and durable. It provides 70% of rural energy requirements in Haiti (Lea, 1996), 70% - 90% in India (Patel, 1986; Saxena and Ventashwarlu, 1991) and similar high levels of use in Peru (Diaz, 1995). Making of *P. juliflora* charcoal supports livelihoods of 150,000 people and generates over 50 million USA dollars per year in Peru (Lea, 1996). The Forest Department in India produces and markets *P. juliflora* charcoal through special development corporations. In Gujarat state alone, an estimated 3 million tons of charcoal are produced per year, creating 55,500 man-days of employment per year (Kanzaria and Varshney, 1998). In addition, one district in Peru produces between 3,000 – 16,000 tons per year of charcoal. In India attempts have been made to generate electricity by burning of wood or through gasification (Patel, 1986; Parker, 1999). *P. juliflora* produces high quality charcoal with high caloric value from 4200- 5065 Kcal/kg (Pasiecznik *et.al.* 2001). The wood does not spark, or emit much smoke and burns slowly with hot and even heat with specific gravity 0.70 or higher. Hence it is called wooden anthracite (Pasiecznik *et.al.* 2001).

Its branches are widely used as fencing posts. It has been used as live fence both in introduced and native countries (Kanzaria and Varshney, 1998). The plant can also be used as shade around houses, road sides and schools.

Empirical studies conducted in Sudan indicate that wind speed inside a five-year-old *P. juliflora* plantation was reduced by an average 14%, while potential evaporation was reduced by 22% (El Fadl, 2007). *P. juliflora* improves soil texture and soil organic matter under their canopy. Soils under the canopy have higher total nitrogen and available phosphorus, and lower soil pH than soils in the adjacent open field (El Fadl, 2007). Similar studies in the Njemps flats of Kenya's Baringo district, reveal that standing biomass of understory plant species were five times lower under the *P. juliflora* canopy (Felker, 2003). Plant cover was also lower under *P. juliflora* than in the open areas. Organic carbon and total nitrogen concentrations in soils under *P. juliflora* were 13% and 45% higher than in the open areas. An evaluation of the comparative performance of *P. juliflora* against other tree species such as *Albizia lebbec*, *Azadirachta indica*, *Dalbergia sissoo*, *Morus indica*, *Populus deltoids*, *Syzigium cuminii* and S*yzigium fructicosum* found that *P. juliflora* seedlings had the highest survival rate, height gain, girth growth and the highest primary biomass production (Baumer, 2008).

Fruits of *P. juliflora* are sweet, nutritious, and have low concentrations of tannins and other unpalatable chemicals (Abiyot and Getachew, 2006). Pods were commonly chewed fresh or roasted, pounded in pestles or stones into flour. The flour was used in a variety of ways such as baking bread, making gruel, making fresh drinks (*anapa* or *yupisin*) or even fermented (*aloja*) in Peru (Patel, 1986; Lea, 1996). Although they have low concentrations of unpalatable chemicals such as tannins and poly phenols, they contain nearly all the essential amino acids present in acceptable nutritional quantities of standard protein (Perrings *et.al.*, 2002). High sugar contents of the pods enhance the activity of rumen bacterial cellulose (Felker, 2003).

Pods of *P. juliflora* have high sugar and protein content (Felker, 2003). There have been no anti-nutritional factors detected in the pods in regard to human consumption (Becker and Grosjean, 2009). Flour made from *P. juliflora* pods has moderate protein content of 8.3% and very high levels of carbohydrate content of 73% (Crooks, 2002). The amino acid profiles of *P. juliflora* pods contain essential amino acids that are not found in most other legume plant seeds. The pods can also be processed to produce flour, coffee, alcoholic drinks, and ice cream (Talpada and Shukla, 1988).

The pods have potential to produce liquid fuel and destructive distillation of dry wood produces 33.9% charcoal, 1.24% methanol and 124.8 liter/kg of gas (Talpada and Shukla, 1988). *P. juliflora* wax can be used in industrial and pharmaceutical industry as raw material for production of candles, furniture polish, creams and balms (Durr, 2001). On average 40 g of gum is produced from one plant per year.

The flowers are good bee forage producing pollen and nectar that is high in protein and sugar (Dennill *et.al.*, 1999). Honey yields of between 100-400 kg/ha/year have been reported in Brazil (Silva, 1990) and 225 tons of honey/year in Hawaii (Esbenshade, 1980). The high flowering potential of *P. juliflora* and its bright flowers have been found to attract native pollinators to the detriment of other native flora.

P. juliflora wood has excellent structural stability and pleasant appearance hence it is increasingly finding use in the manufacture of furniture handles of agricultural and household implements due to their strength, hardness, and toughness (Tewari, 1998). However, their short and often crooked stems need the use of specially designed chain-saw tables or micro-sawmills (Pasiecznik *et.al.,* 2001) hence a limitation.

P. juliflora has medicinal value. In India, the bark extract is used as an antiseptic on wounds, while the gum is used to treat eye infection (Patel, 1986). Because of bactericidal and fungicidal effects, the plant extracts are widely used to treat eye infection, stomach disorders, skin ailments and superficial wounds. In Guatemala, *P. juliflora* is used to treat sexual transmitted diseases such as *Neisseria gonorrhoea* and crushed leaves of the plant are known to be used as suicidal agent in India and incidence of poisoning is common in rural areas. *P. Juliflora is* also used as remedy for colds, diarrhoea, dysentery, flu, headache, inflammation, measles, and sore throat (Pasiecznik *et.al.* 2001).

2.5 Impact of *P. juliflora* on soil nutrients.

P. juliflora is a leguminous plant which fixes nitrogen through symbiosis, hence it can directly affect soil nitrogen dynamics (Frias-Hernandez *et.al.*, 1999). There have been reports of higher levels of nitrogen in soils underneath *P. juliflora* canopies than those in open areas (Klemmedson and Tiedemann, 1986; Frias-Hernandez *et.al.*, 1999; Geesing *et.al.*, 2004). In Mexico, it has been reported twice as high levels of nitrogen under *P. laevigata* in open areas. (Frias Hernandez, *et. al.* 1999). It was also reported to be three times greater nitrogen content under *P. juliflora* canopies in low rainfall savanna soils (Klemmedson and Tiedemann, 1986). In the California desert *P. glandulosa* has been shown to fix 30 kg Nitrogen per ha per year (Geesing *et.al.* 2004). The higher concentration of nitrogen under *P. juliflora* canopy can be attributed to the deposition of nitrogen enriched litter (Frias-Hernandez *et.al.*, 1999). Due to its extensive root system *P. juliflora* is able to absorb ammonium and nitrate ions from outside its canopy area and concentrate nitrogen in its tissue. Additionally *P. juliflora* has the ability to form symbiotic relationships with nitrogen-fixing Rhizobium, thus increasing the nitrogen content of its litter and the cycling of nitrogen under its canopy (Frias-Hernandez *et.al.*, 1999). *P. velutina* has been reported to accumulate nitrogen at the rate of 112 g/m2 per metre of height in a three year experiment in the Sonoran desert (Klemmedson and Tiedemann, 1986).

Several studies have reported significantly higher carbon content in soils associated with *P. juliflora.* In the desert grasslands of south eastern Arizona, soils under *P. juliflora* had significantly higher carbon content than those in areas where *P. juliflora* had been removed (Klemmedson and Tiedemann, 1986). In central Mexico, total carbon content doubled in soils under *P. laevigata* than in open ground (Frias-Hernandez *et.al.* 1999). *P. laevigata* was also found to increase the organic content of soils beneath its canopy in the same area. Klemmedson and Tiedemann (1986) reported three times greater carbon content under the canopy of *P. juliflora* in low rainfall savanna soils. Carbon accumulation under *P. juliflora* is higher than in the open due to absorption of bicarbonate and carbonate ions from outside the soil-plant systems by the plants' extensive root systems (Barth and Klemmedson, 1982). Soils under *P. velutina* have been found in a three year study to accumulate carbon at the rate of 0.11 kg/m^2 per metre of tree height in the Sonoran desert of the USA (Barth and Klemmedson, 1982).

P. juliflora plants tend to accumulate soil nutrients beneath their canopies (Barth and Klemmedson, 1982). This accumulation may result from several processes that include (a) absorption of nutrients by roots from beyond the crown area of the plant or from lower soil layers and substratum and eventual deposition of the litter under the crown, (b) fixation of nutrients by the plant or an associated symbiotic organism, (c) net import of nutrients by fauna that use the plants for nesting, resting, roosting or feeding, (d) movement by wind or water (Barth and Klemmedson, 1982). However, since *P. juliflora* trees seem to enrich the soils under their canopies at the expense of the soil nutrient capital in the open areas, the overall nutrient status of invaded rangeland may compare un-favourably with un-invaded or cleared rangeland. Studies conducted in the desert grasslands of the south western USA have shown that clearing of *P. juliflora* increases the amount and duration of supply of soil moisture (Klemmedson and Tiedemann 1982). This is because *P. juliflora* trees use two to three times more water than natural herbaceous vegetation. This effect may be felt both beneath the trees and in the open as *P. juliflora* roots extend downwards and laterally (Klemmedson and Tiedemann 1982). Moisture depletion occurs rapidly near *P. juliflora* tree bases with depth and distance from the tree (Jacoby and Ansley, 1991). Studies in the rangelands of southern Arizona in the USA have found significant increases in moisture content of the upper 45 cm of soil at distances of 3, 6 and 10 metres from dead *P. juliflora* trees compared to live ones.

2.6 Control and management of *P. juliflora*

Experiences from America, Asia and Australia have shown that eradication of *P. juliflora* has proven to be very difficult or sometimes considered impossible. This is largely because the trees re-grow from vegetative buds and from massive underground seed banks, with seed production in dense stands estimated at 60 million per hectare per year (Pasiecznik *et.al.* 2001). Seeds usually lie dormant in the soil for up to 10 years. Mass germination is stimulated when the surrounding vegetation is removed or the soil is disturbed. *P. juliflora* management and control programmes therefore need to be sustained for long periods to gain total control of the spread, and are very costly (Pasiecznik *et.al.* 2001).

Mechanical control of *P. juliflora* involves physically uprooting, clear felling or ring barking the trees. It was the first method used in pasturelands in the USA. However it is very expensive and only cost effective on a small scale in smallholdings of high value. Caterpillar tractors uproot the trees by chaining. It has a treatment life span of 20 years or more (Jacoby and Ansley, 1991). Opening up of the canopy and soils, stimulates massive germination and coppicing. Chemical control of *P. juliflora* involves use of systemic herbicides on cut stems of *P. juliflora* or aerial spraying of young trees. The herbicide of choice in USA and Australia was 2, 4, 5 - T (Jacoby and Ansley, 1991). Infested sites often need repeated spraying after every five to seven years. Other effective herbicides for stump treatment include Clopyralid, Dicamba, Pylori, triclorpyr and ammonium sulphamate. However Glyphosphate Trimesium is effective for folia application only. Chemical control is expensive and environmentally unfriendly. Fire only kills young seedlings because older of *P. juliflora* trees have protective thick bark (Jacoby and Ansley, 1991).

In South Africa, a bruchid beetle *Algarobiuos prosopis* has proved to be successful as a biological control agent (Zimmerman, 1991; Hildegard, 2002). It attacks the seeds in the pods just before they drop off to the ground thus reducing viability of the seeds. It has been used in Australia and South Africa with considerable success. It is environmentally friendly and cost effective. In South Africa, the beetle has managed to reduce the *P. juliflora* seed bank by 70% in open grazing fields as compared to 90-95 % in livestock and game excluded areas introduced since 1987 (Hildegard, 2002).

This study was also governed by various environmental legislations that have been enacted in Kenya including multilateral environmental agreements (MEAs). Hence the study focused on sustainable utilization of the weed and not eradication. This is the view held by National Environment Management Authority (NEMA) and Kenya Forest Service (KFS). The new forest policy seeks to protect the environment through reduced soil erosion; develop carbon sinks by increasing forest cover by 10% and save biodiversity while working with local communities. It seeks to explore opportunities in carbon trade for conservation and management of forests by promoting tree planting and rehabilitation for carbon sequestration (GoK, 2006).

The land policy seeks to promote efficient, sustainable and equitable use of land and land based natural resources to achieve prosperity while protecting natural resources for the benefit of future generations while protecting fragile and critical ecosystems (GoK, 2006). Energy policy advocates for provision of adequate, reliable cost effective and affordable energy supply to meet development needs while protecting and conserving the environment. It seeks to promote fast maturing trees for energy production including bio-fuels and establishment of commercial woodlots and promote carbon credit trade while promoting co-generation of electric power (GoK, 2006). The environment policy therefore seeks to protect and conserve the environment through enforcement of these regulations, procedures and guidelines for sound environmental management. Hence NEMA advocates for sustainable utilisation by generating electricity from the biomass of the weed. A factory has been licensed by NEMA and commercial charcoal production.

Kenya has also ratified the following conventions: The United Nations Framework Convention on Climate Change (UNFCCC) which seeks to achieve stabilization of greenhouse gases; The convention on Biological Diversity (CBD) agenda 21 which aims at sustainable development; and the Convention to Combat Desertification(CCD) which seeks to combat desertification and mitigate effects of draught (GoK, 2006).

Kenya also seeks to achieve the millennium development goals especially to eradicate extreme poverty and hunger and to ensure environmental sustainability. This is laid out in Kenya's vision 2030 strategy which aims at making Kenya a middle level economy with a GDP of 10% ensuring environmental sustainability (GoK, 2006).

2.7 Environmental Impact Assessment (EIA) process

Environmental impact assessment (EIA) is a systematic examination conducted to determine whether a programme, activity or project will have any adverse (negative) or beneficial (positive) impacts on the environment (GoK, 1999). It looks at the project operation stages, state of the ecosystem, socio-economic impacts, and alternatives in the project, risks, and compatibility with existing planning framework. It involves all relevant stakeholders in the planning stage and proposes mitigation measures for adverse impacts predicted. EIA is a planning tool which helps to create sustainable and quality service delivery, sustainable social economic growth, manage pollution and waste, identify critical regulatory mechanisms and manage operational risks (GoK, 1999). It helps to choose alternative technology, alternative sites, alternative inputs that pollute less. Hence it is used for informed decision making. Projects that should undertake EIA include those out of character with the surrounding and those that cause major changes in land use like invasive *P. juliflora* (GoK, 1999).The EIA process in Kenya begun in the year 2000 after enacting the environment law. This was followed by formation of National Environment Management Authority (NEMA) which is in charge of the EIA process. However no EIA was done for *P. juliflora* since it was introduced earlier in 1980 before the EIA process begun in Kenya. EIA process is based on the concept of sustainable development. This is the development that meets the needs of the present generation without compromising the ability of future generations to meet their needs by maintaining the carrying capacity of the supporting ecosystems. However, no EIA was done before *P. juliflora* was introduced in 1983. The EIA process became mandatory in the year 2000 after enactment of the environment law (EMCA 1999).

Table 2.1: Summary of literature reviewed

Author(s)	**Summary of literature reviewed**
Raghubanshi *et.al.* 2005; Haysom and Murphy 2003; IUCN, 2004; CBD, 2001	• Definition of alien invasive species • Impacts of alien species
Essa 2006; Kathiresan2008; Baillie2004	• Impacts of alien species
Sharifi *et.al.* 2000; Pasiecznik *et.al.* 2001	• Characteristics of *P. juliflora*
Meyerhoff1991; Choge et.al. 2002	• History of *P. juliflora* trials in Marigat
Tiwari and Rahmann1999	• Uses of *P. Juliflora*
IUCN, 2004	• Invasive alien spp, in Kenya
Pasiecznik *et.al.* 2001	• Global invasion of *P. juliflora*
Sala *et.al.* 2006	• Benefits of invasive plants.
Baumer,1990; Hulme, 2012	• Allelopathic effects of *P. juliflora*
Jhala1993	• Negative impacts of *P. juliflora*
Roach, 1990; Vimal & Tyagi, 1986	• Medicinal value of *P. juliflora*
Dennill et.al. 1991; Esbenshade,1980; Silva,1990	• Potential of *P. juliflora* for honey production
Kanzaria and Varshey, 1998; Lea, 1996; Talpada and Shukla, 1988	• Production of bio-fuels from *P. Juliflora*

2.8 Theoretical framework

The theoretical framework of this study was based on the theory of island biogeography by Macarthur 1967 and the concept of Harding 1967 on the Tragedy of the Commons. This was further supported by the cost benefit analysis theory. The equilibrium theory of island biogeography states that species richness is maintained by equilibrium between opposing rates of colonization, speciation and extinction (Mac Arthur, 1967). It explains major factors that affect species diversity on islands and other isolated habitats. The equilibrium between extinction and immigration rates is determined by two major factors: distance from the mainland, and island size. Large islands can support more species and have lower extinction rates than small islands because they cover larger areas with a greater diversity of habitats and resources. Less isolated islands tend to support species than remote ones because they have higher rates of immigration. However, the argument against this theory is that introduced invasive plants do not follow island biogeography prediction as they exceed it by far and are a cause of extinction. Islands are prone due to lack of natural competitors and predators that control population in their native ecosystem (MacArthur *et. al.* 1967).

The second theory is the invasive meltdown theory. This theory states that species are added to an ecosystem each one representing a potential disturbance. The native system is perturbed in such a way that the system reaches a threshold at which it cannot resist any further and invasions occur exponentially. Each individual invader is a threat, but it is their collective impacts that can cause the greatest damage to a habitat. This phenomenon is called invasion cartel and creates the meltdown theory (MacArthur *et.al.* 1967).

Lastly the Harding's theory of the Tragedy of the Commons is significant in this study as land is communally owned and people have no incentive to manage the spread of *P. juliflora* in communal pastureland. Peoples' perceptions of invasive species depend upon whether their economic needs are met. Private property rights may serve to create substantial incentive for investment in resource management. Cost-benefit analysis (CBA) is often suggested as an appropriate framework to objectively assess the relative desirability of competing alternatives in terms of their economic worth to society (Boardman 2006). CBA is one of a few partial-equilibrium methods available within welfare economics for determining the monetary values of the impacts caused by invasive alien plants on society and for evaluating options for their management. Well designed CBAs account for externalities, uncertainties, and equity and can evaluate the welfare effects of managing invasive plants. The only disadvantage with CBA is that it must assign monetary values to all benefits and costs but some are intangible in environment hence difficult to evaluate (Boardman 2006). CBA uses the concept of discounting present values into future values.

$$\text{Present value (Pv)} = \frac{P_t}{(1+r)^t}$$

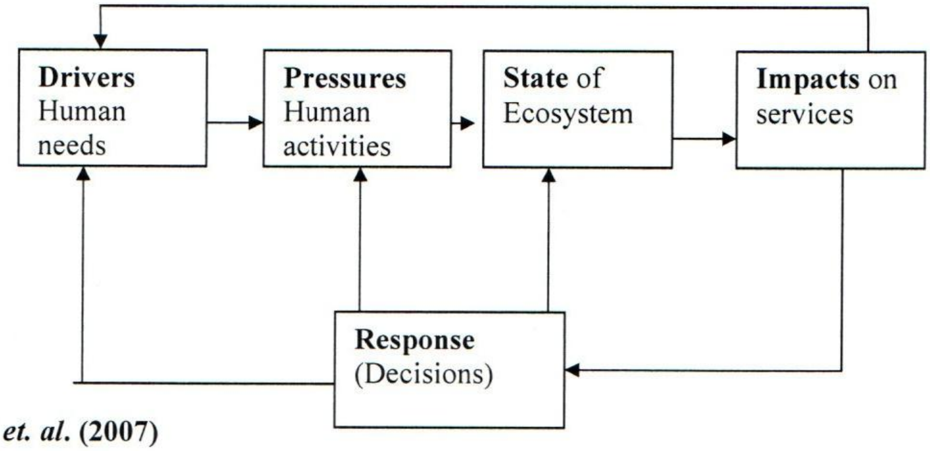
Invasive *P. Juliflora* has no opposing rate of colonization. It exceeds any form of colonization since it is the cause of extinction of other species hence the equilibrium theory of island biogeography does not adequately explain its invasion. The theory of the tragedy of the commons is only applicable when explaining why communities are unable to manage communal resources. However the meltdown theory which states that invasion adds more plants until the ecosystem reaches a threshold and further invasion occurs exponentially explains the invasion of *P. Juliflora* adequately. *This exponential invasion* causes damage to the ecosystem which is the invasion cartel.

2.9 Gaps in literature

From the preceding literature review, it is evident that little research has been done on the impacts of *P. juliflora* on the environment, pastoral communities and their livestock in Kenya. The extent of invasion of the tree and impacts it causes on land use changes have not been documented. Literature cited had little on cost benefit analysis of the weed in Salabani. No formal EIA was conducted by the government of Kenya before introducing *P. juliflora* since it was not mandatory by 1983. The government therefore did not look at the nature of invasion of the tree and the impacts it causes on land use and ecology. Hence no mitigation measures were put in place to manage the invasion of the tree.

2.10 Conceptual framework

This study was anchored on the Drivers-Pressures-State-Impact-Response conceptual framework (DPSIR Frame Work derived from OECD 1994).



Source: Wei, J. *et. al*. (2007)

Figure: 2.1 DPSIR Conceptual frame work model by OECD 1994

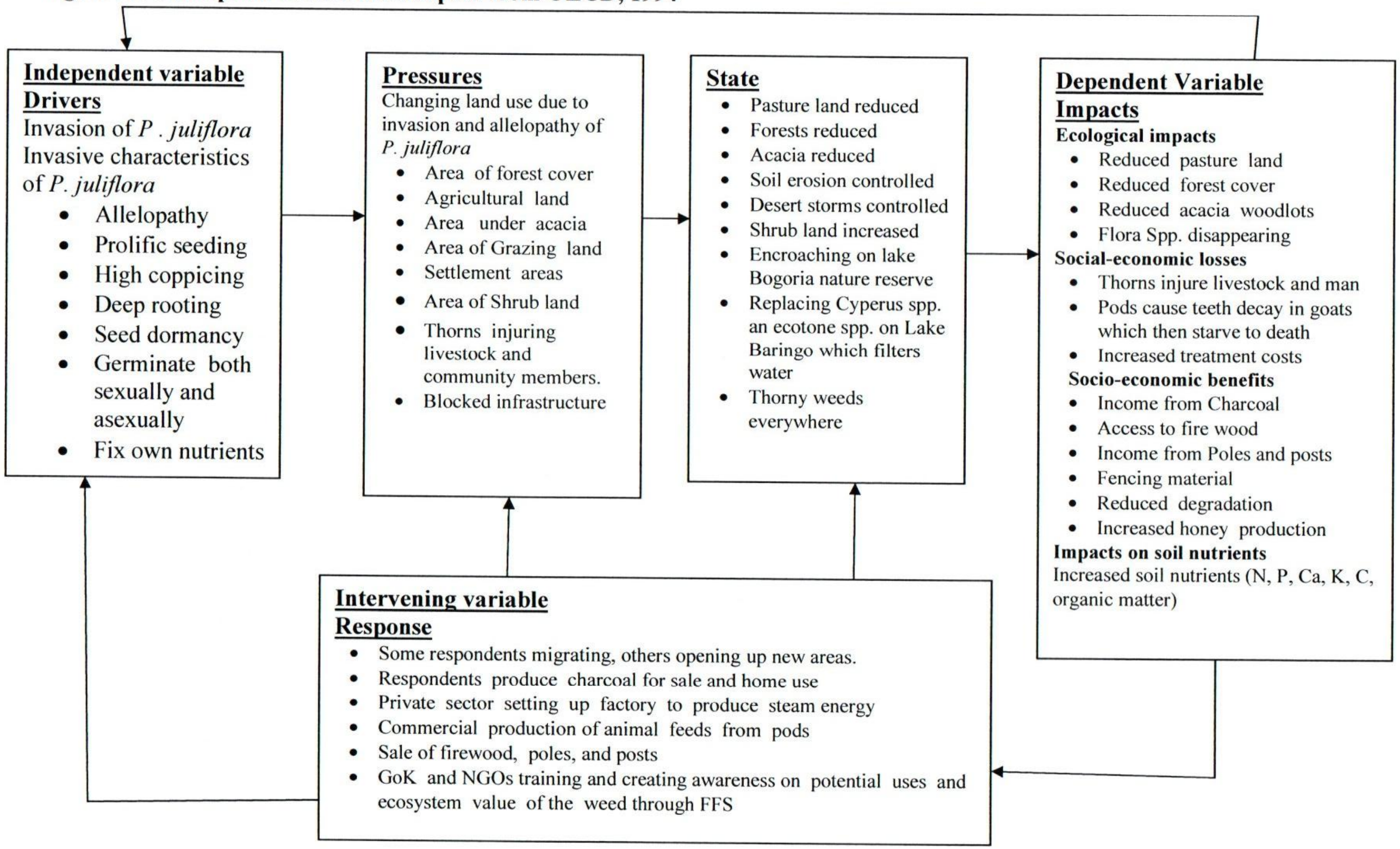
This framework was initially developed by Organization for Economic Co-operation and Development (OECD) in 1994. It is a flexible framework used in decision making process for alternative wise use of natural resources for sustainable development.

DPSIR Frame Work defines drivers as socio-economic factors that are necessary to fulfill human needs for food, water, shelter, health, security and culture. These are social demographic and economic developments in societies and the corresponding changes in life styles. In the case of Salabani Location the human needs focused upon seeking alternative vegetation cover that would help control land degradation, control soil erosion, control desert storms, provide source of fuelwood and be an alternative income generating crop. However, the plant became invasive by spreading in all land use systems hence affecting the way of life of the residents. Therefore, the invasion of P. *juliflora* is the driver in this model and hence it is the independent variable upon which all other factors depend. This study thus investigated impacts of the invasive *P. juliflora* on the socioeconomic welfare of the people of Salabani Location.

These drivers then put pressure on the environment intentionally or unintentionally leading to land use changes, resource depletion through consumption, or physical damage through direct contact or uses of the resource like the harmful thorns of *P. juliflora*. In this case therefore, the pressure is change of land use due to the invasion of the weed and the resulting changes lead to reduced forest cover, reduced pastureland and reduced acacia woodlots for these pastoralists. The pressures exerted may lead to changes in the state of the ecosystem which may affect the abiotic and biotic components, and the way of life of the local communities in Salabani Location.

These changes usually are unwanted and are thus perceived to be negative like change of habitat, loss of pastureland and loss of acacia woodlots. When the state of the ecosystem changes goods and services are affected. Changes in quality, quantity and functioning of the ecosystem, impact on the social welfare of mankind (dependant variable). Ultimately human beings make decisions in response to the impacts on ecosystem services or their perceived value. Responses could be in form of action by individuals migrating from the area or burning charcoal from the plant for sale, groups or government trying to prevent, compensate, ameliorate or adapt to changes in the state of the environment by seeking to control drivers or pressures through regulation, prevention or mitigation. Private entrepreneurs could come in inform of commercial charcoal producers, steam energy producers, collection of wax for the pharmaceutical companies, animal feed manufacturers, or private pod collectors.(Figure 2.3).

Figure 2.2 Conceptual framework adopted from OECD, 1994



CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter examines related aspects of research methodology. This includes definition of the study area, type of research design, types of data collected, the sample frame, sample size, sampling procedure, sources of data, instruments and data collection methods, methods of data analysis and presentation.

3.2 Study area

The study was conducted in Salabani Location, Marigat Division in Marigat District of Baringo County in Kenya (see Figure 3.1). Salabani location is one of the 14 locations making up Marigat Division. The study area is located about 15 km from Marigat town along the Nakuru - Marigat - Kambi Samaki road at a junction near Endao Bridge. This location lies between two Lakes namely Baringo and Bogoria. These are the floodplains of the Ilchamus also known as Njemps. Salabani location is an ASAL area where the main economic activities of the local community are apiculture and pastoralism. The study area experiences severe soil erosion problems due to poor vegetation cover. The soil structure is poorly developed leading to poor infiltration and loss of rainwater and soil erosion through run-off (GoK, 2002). Soils are mainly clay loams with alluvial deposits derived from tertiary / quaternary volcanic and pyroclastic rock sediments that have been weathered and eroded from the Tugen uplands towards Kabarnet. The soils in the study area contain high levels of phosphorous, potassium, calcium and magnesium, though they are reported to contain low levels of nitrogen and carbon (GoK, 2002). These soils are known to range from acidic to slightly alkaline (GoK, 2002).

Salabani receives bimodal rainfall. Long rains start from March to July while short rains between September and November. These lowlands receive 600 mm of rainfall annually which is low erratic and unreliable. The mean annual maximum temperature lies between 25°C and 30°C. The hottest months range from January to March. The mean annual minimum temperatures vary from 16–18°C (GoK, 2002). The region lies between agro-ecological zone IV and V. Vegetation in the study area is comprised of *P. juliflora*, Acacia woodlots (mainly *A. tortilis*) in association with *Boscia* spp., *Balanites aegyptica* and bushes of *Salvadora persica*. High evapo-transpiration rates and low variable rainfall create water scarcities that limit intensive agricultural land use (GoK, 2002). The population density is relatively low 21 persons per square kilometer, with a total population of 40,985 people in Marigat division (GoK, 2009). Salabani location has 2000 households (6,620 people) who belong to two tribes the Njemps (Ilchamus) who belong to the Maasai tribe or Tugen of the Kalenjin tribe.

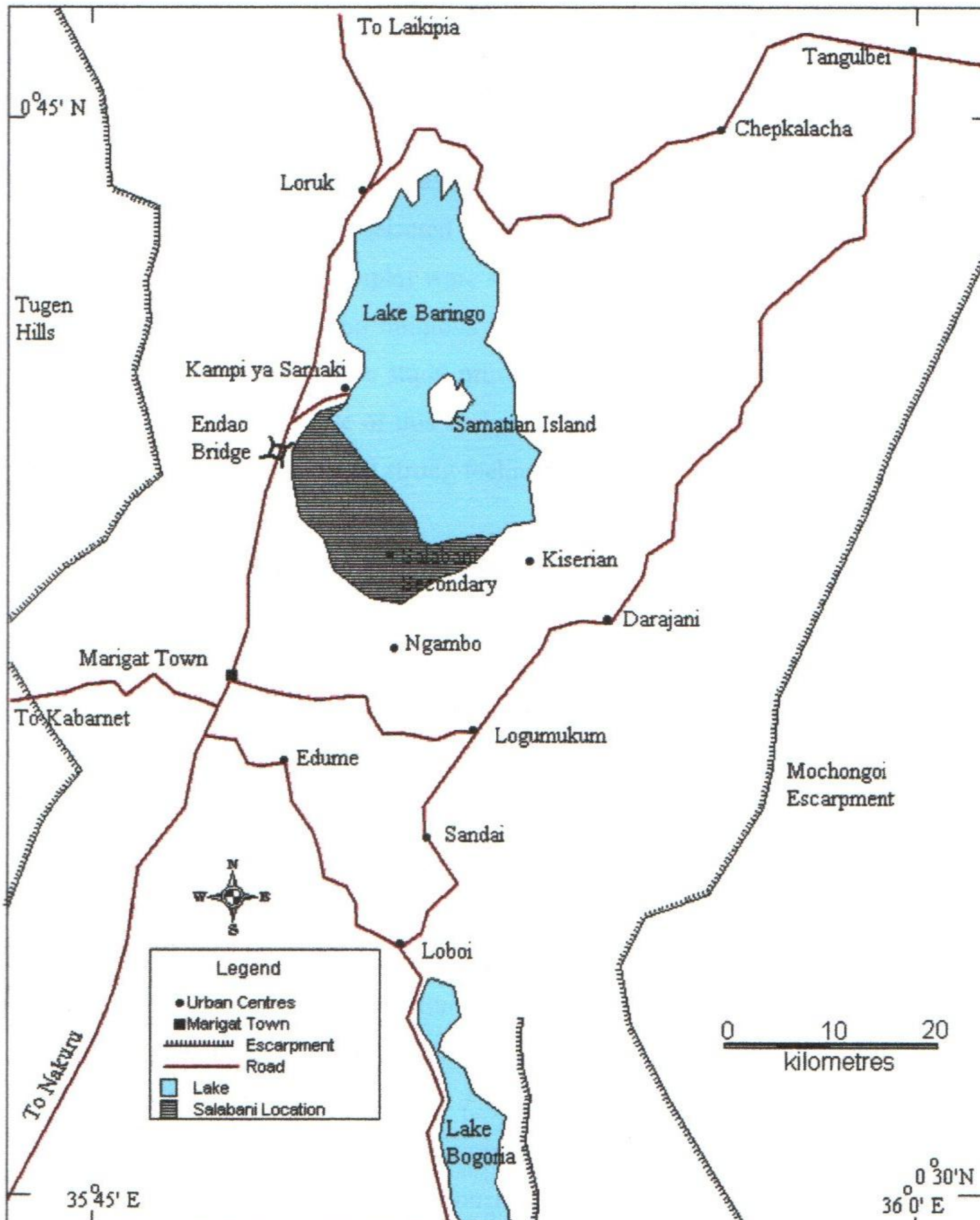


Figure 3.1 Map of the study area.

Source: Moi University, Geography Department, 2012

3.3 Research Design

This study relied on a cross-sectional survey design. This is a descriptive design that collects data on a sample of the population which is then used to make inferences about the population under study. They are normally used to systematically gather factual quantifiable information necessary for decision-making. Surveys are efficient methods of collecting descriptive data regarding the characteristics of populations, current practices and conditions or needs. They also help gather information from large cases by employing use of samples hence cutting down on costs (Kothari, 2004). Given the above stated attributes, cross-sectional survey research design was adopted in this study in order to capture qualitative and quantitative data from the selected samples and generalize the findings to the target population. In this design, samples were studied using questionnaires as an instrument of data collection. The responses and opinions from the households, community members and the experts that participated in the study provided an impression on what actually exists in the study area. The disadvantage of this design is that it is difficult to remember past events and respondents have their personal strong feelings to issues under study (Kothari, 2004).

3.4 Types of Data and Research Variables

Nature of data to be collected is an important component of research. This study relied on both primary and secondary data. To determine the extent of invasion of *P. juliflora* and impacts on land use and ecology the study collected data on changes in Land use patterns using satellite images between 1998 and 2012, types of flora and fauna emerging or disappearing due to invasion of *P. juliflora*. To determine Economic costs and benefits associated with this plant, data was collected on costs incurred due to thorns of *P. juliflora* puncturing bicycle and vehicle tyres and costs involved per household per annum, number and value of livestock that have died or have been injured by *P. juliflora* thorns, number of people in the sample households injured by *P. juliflora* thorns, types of injuries and cost of treatment, types of infrastructure blocked or damaged by *P. juliflora* like roads and water pipes, number of people displaced by *P. juliflora* and value of development on homesteads vacated. The study also collected data on economic benefits associated with products of *P. juliflora* by examining amount and monetary value of products used like: charcoal, timber, firewood, honey, posts and poles per household per annum.

To determine relationship between soil nutrients and spread of *P. juliflora,* soil samples were collected and analyzed for soil pH, electrical conductivity, organic matter and concentrations of the following minerals; carbon, potassium, phosphorous, sodium, calcium, and nitrogen.

.

3.5 Study Sample Population, Sample Size and Sampling Frame

The study targeted all the households living in Salabani location of Marigat division in Baringo County. From the population census of 2009, there were 2000 households living in this location (GoK, 2009). A list of all the 2000 households was obtained from the population census report. The households were then given numbers which were fed to STATISTICA 6.0 computer program to generate a list of random numbers for each household. From the random numbers generated, a sample population of 200 households was randomly selected which gives a 10% sampling intensity. This lies between the accepted sampling intensity of 5% to 10% for social science surveys (Alan and Barbara, 1986). The sample population was randomly selected to ensure that every household had an equal chance of being selected to avoid bias. This study therefore used simple random sampling technique which represents probability sampling. In addition, another 15 key informants comprising of government and NGO officials and opinion leaders from the study area were sampled based on their expert information. This constituted non probability sampling.

3.6 Research Tools /Instruments of Data Collection

In this study both primary and secondary data were collected using questionnaires, focused group discussions with key informants, direct observations, photography, soil sampling and Land Sat TM images. The selections of these tools were guided by the objectives of the study and nature of data to be collected. Both open and closed ended questions were prepared and pretested as a questionnaire. Questionnaires allow for precision and efficiency in coding (Kothari, 2004). Questionnaires would also avail the opportunity for the respondents to give frank response while maintaining anonymity except when disclosing their gender. Two types of questionnaires were prepared and used in collection of data in Salabani from households and key informants like government and NGO officials and opinion leaders for their expert information. Two hundred questionnaires were administered to the targeted sample population in Salabani location with the help of two research assistants.

Data was also collected through direct observation for blocked infrastructure and amenities, undergrowth, presence of fauna nesting under *P. juliflora* stands in the study area, presence of charcoal kilns and beehives. A digital camera was then used to capture unique observations like uses of *P. juliflora*.

Soil samples were collected for nutrient analysis using Stratified systematic sampling. The study area was stratified into three layers based on density of *P. juliflora* stands. These were high density, low density and where there was no *P. juliflora* (zero density). Each stratum was sampled into a composite sample separately. The amount of exchangeable sodium and potassium in the extract were determined by flame photometry whereas calcium by atomic absorption spectrophotometry.

3.7 Validity and Reliability of the Research Tools

Validity refers to the extent to which a test measures what was actually intended to measure (Mugenda and Mugenda, 1999). The researcher pre- tested the questionnaire as a tool of data collection on five respondents in Salabani Location to confirm whether the questions accurately measured the intended variables. This was done by pre-testing the questionnaire instrument before commencing the research in 2009. It yielded a reliability coefficient of 0.80 hence the questionnaire was found reliable.

3.8 Data analysis

Primary data gathered was coded and keyed into the computer for subsequent analysis using SPSS version 9.0 computer programme. Data was analyzed by use of both descriptive and inferential statistics. Descriptive analysis involved measure of central tendency like means of population characteristics. The rate of spread of the weed in different land uses due to coppicing was analysed using analysis of variance (ANOVA). Analysis of Variance was also used to compare various soil nutrients in different stands of *P. Juliflora* based on densities. Likert score ranking was used in evaluating preferences of various uses of the plant. Cost/benefit analysis was used to compare benefits and costs of *P. juliflora*. .

$$\text{Present value (Pv)} = \frac{P_t}{(1+r)^t}$$

Where PV is present value, r is the interest rate, Pt is the value in future time t

$$\text{The Net Present value (NPV) of a project is} = \frac{\text{sum net (benefits- costs)}}{(1+r)^t}$$

NPV, IRR and Cost/Benefit Ratio (CBR) were then calculated

Table 3.1 Summary of Data Analysis

No.	Objective	Key variables	Analysis
1	To determine extent of invasion of *P juliflora* and impacts on land use and ecology	Area covered Coppicing rate Land use types Changes in Land use Species count	Descriptive analysis ANOVA of different land uses, Trend analysis
2	Determine costs and benefits of *P. juliflora*	Uses of *P. juliflora* Value of products Cost of treatment Cost of repairing bicycle tyres	Likert score ranking Cost/ benefit analysis
3	Relationship between soil characteristics and invasion of *P juliflora*	pH, EC, Ca, N, P, Na, K, C, Organic matter	ANOVA of different *P. juliflora* stand densities

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents findings and discussions of the study based on three specific objectives namely: extent of invasion of *P. juliflora* and impacts on land use and ecology; costs and benefits of *P. juliflora*; and the relationship between soil characteristics and the spread of *P. juliflora* in Salabani Location. The chapter also discusses the socio-economic background of the sample population as relates to invasion of *P. juliflora.*

4.2 Socio-Economic Background

In this section the study presents the social economic characteristics of the population sampled. This includes distribution of population by age, gender, marital status, occupation and levels of education.

4.2.1 Distribution by Age

Table 4.1: Age distribution of the local community and key informants

	Local community		**Key informants**	
Age (Years)	Frequency	Percent	Frequency	Percent
19 years & below	10	5.0	0	0.0
19-25	56	28.0	1	6.7
26-35	58	29.0	3	20.0
36-55	52	26.0	6	40.0
55 & above	24	12.0	3	20.0
Total	200	100	15	100.0

Source; Survey Data, 2009

Table 4.1 shows the age distribution of the sample respondents. It may be observed that most of the respondents sampled (62%) were youth aged 35 years and below. Most of the adult members of the households (36 years and above) were hardly found at home due to their nomadic pastoral way of live and spend most of the time away from home. 62% of the youth sampled felt *P. juliflora* was beneficial whereas 38% felt it should be eradicated. Only 38% of the sample respondents were adults. 33% of adults sampled were of the opinion that

P. juliflora is beneficial whereas 67% felt it should be eradicated. The youth are engaged in charcoal production hence appreciate the importance of the plant.

4.2.2 Distribution by gender

Table 4.2: Distribution of the sample respondents by gender

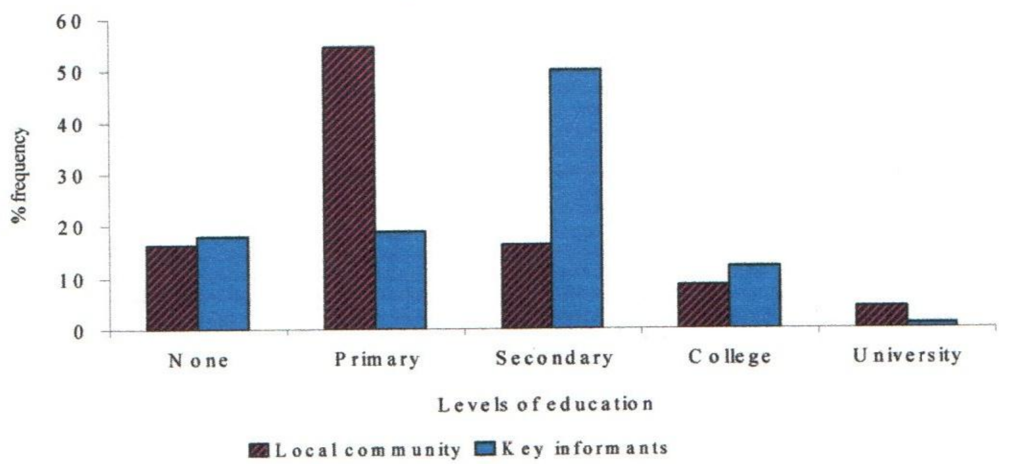
	Gender	Frequency	Percent
sample respondents	Male	114	57
	Female	86	43
Key informants	Male	13	86.7
	Female	2	13.3

Source: Survey Data, 2009

Table 4.2 shows the distribution of sample respondents by gender. It may be observed that of the population sampled 57% were males and 43% females. These figures suggest that there were more males sampled than females to the ratio of 1: 0.75. 69 % of the females sampled felt *P. juliflora* was beneficial as it was a source of firewood whereas 31% felt it should be eradicated. On the other hand, 65% of the males felt it should be eradicated because of the impacts on livestock their main economic activity whereas 31% found it beneficial. The female in this study area spent time collecting firewood hence the weed has reduced the time and distance in search of firewood. This explains why womens' preference for *P. juliflora is* higher than men. Men value their livestock most and because the weed causes teeth decay in goats which starve to death their preference for the weed is low.

4.2.3 Distribution by Levels of Education

Figure 4.1: Educational levels of respondents



Source: Survey Data, 2009

Figure 4.1 shows levels of education of the sample respondents. 17% had no formal education, 55% had education upto primary level, and 17% had education upto secondary level whereas only 13% had education beyond secondary school level. Level of education is low in this region as these are pastoralists whose livelihood is livestock keeping. The problem of cattle rustling with neighbouring communities keeps them away from schools. 57% of the respondents who had some form of education beyond primary level felt *P. juliflora* was beneficial and 43% felt it should be eradicated. Whereas 74% of those respondents with no form of education felt *P. juliflora* should be eradicated.

These results suggest that because of low levels of education, awareness levels could also be low on appreciating other potential uses of *P. juliflora.* The older and less educated members of the population could also be unwilling to change from traditional pastoralism to any other economic activity like charcoal burning. Level of education is thought to help communities change perceptions and this could be the reason may be why the youth with some form of education felt the plant is beneficial because they seem to appreciate the economic potential of the weed especially for charcoal production. The older generation, majority of whom have no form of education, also find charcoal burning a tedious exercise and would prefer pastoralism and bee keeping.

4.2.4 Distribution by Occupation

Table 4.3: Distribution of sample respondents by occupation

	Local community		**Key informants**	
Occupation	Frequency	Percent	Frequency	Percent
Pastoralists	172	86	3	20
Business people	15	7.5	3	20
Teachers	10	5	2	13.3
Clerks	3	1.5	0	0.0
Managers	0	0	2	13.3
Health workers	0	0	1	6.7
Forest officers	0	0	2	13.3
Administrators	0	0	2	13.3
Total	200	100.0	15	100

Source: Survey Data, 2009

Table 4.3 shows the distribution of the sample respondents by occupation. It may be observed that 86 % of the sample respondents were pastoralists. This explains why they view the invasive weed negatively. Their livelihood mainly depends on keeping livestock in large numbers and harvesting honey. If they could be encouraged to produce charcoal on a commercial scale and sell poles and posts of *P. Juliflora* their perception of the plant could be fairly positive.

4.3 Impacts of invasion of *P. juliflora* on Land use and ecology.

Table 4.4: Area of Land Cover Changes.

	1998		**2005**		**2012**	
Land cover	**Area (ha)**	**% cover**	**Area (ha)**	**% cover**	**Area (ha)**	**% cover**
P. juliflora	2906	4.2	4986	7.3	8555	12.4
Forest	16572	24.1	11572	16.8	7101	10.3
Shrub land	17556	25.5	31555	45.9	56704	69
Agricultural land	440	0.6	1940	2.8	3845	5.5
Acacia	13,045	19.0	4164	6.1	1328	1.9
Grazing land	12749	18.5	8656	12.6	7609	11
Settlements	5479	8.0	5874	8.5	6297	9.1
Total	68747		68747		68747	

Source; DRSRS, 2012

The first objective of this study was to determine the extent of spread of the invasive *P. juliflora* and the resultant impacts on land use and ecology of Salabani Location. Table 4.4 shows the land use cover as at 1998 and how it has consequently changed due to the impacts of the spread of the invasive *P. juliflora* in 2005 and 2012.

It may be observed from the satellite images of 1998 in plate 4.1 that there were seven types of land use classes in Salabani Location namely: *P. juliflora* cover, grazing land, acacia woodland, shrub land, settlement areas, forest cover mainly riverine forests and agricultural land.

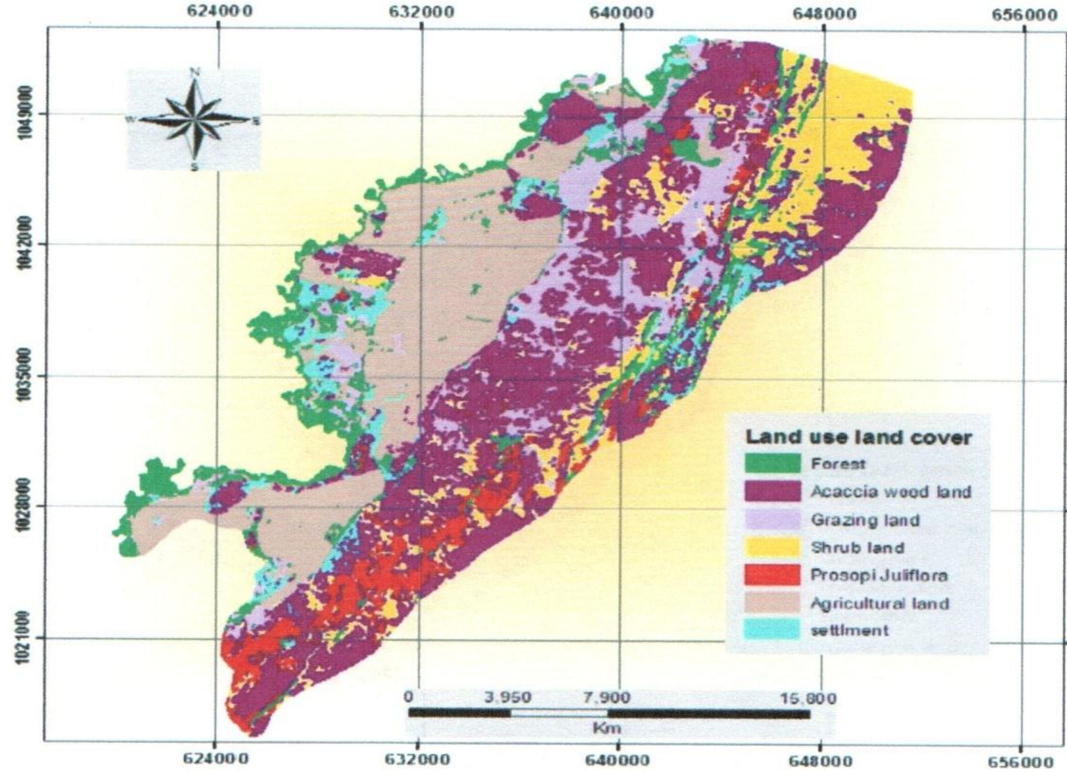


Plate 4.1: *P.* Satellite Imagery of the land use/ land cover map of the study area in 1998 Source DRSRS, 1998

The satellite image indicates that by 1998 the total land cover of the entire study area was estimated to be 68,747 ha. Out of this total land area in Salabani location, it was found out that *P. juliflora,* the invasive weed, had only covered a total area of 2,906 ha in 1998. This is a small area representing only 4.2 % of the total land cover as compared to the outcry by the respondents and the wide media coverage on the spread of the weed in the study area. Comparatively in Australia *P. juliflora* is estimated to have covered 800,000 ha (Pasiecznik et.al. 2001).

The satellite image of 1998 also indicates that land under forest cover was 16,572 ha, shrub land cover 17,556 ha, agricultural land 440 ha, acacia woodlots 13,045ha, grazing land 12,749 ha and land under settlement was 5,479 ha.

However, by 2012, a span of 14 years, it may be observed that *P. juliflora* had spread to 8,555 ha of land which represents 12.4% of the total land cover. This implies that *P. juliflora* is spreading at 403 ha per year or 66%. This rate of spread is very fast and thus confirming that *P. juliflora* is actually an invasive species. No wonder it was declared a noxious weed in Ethiopia (Catterson, 2003).

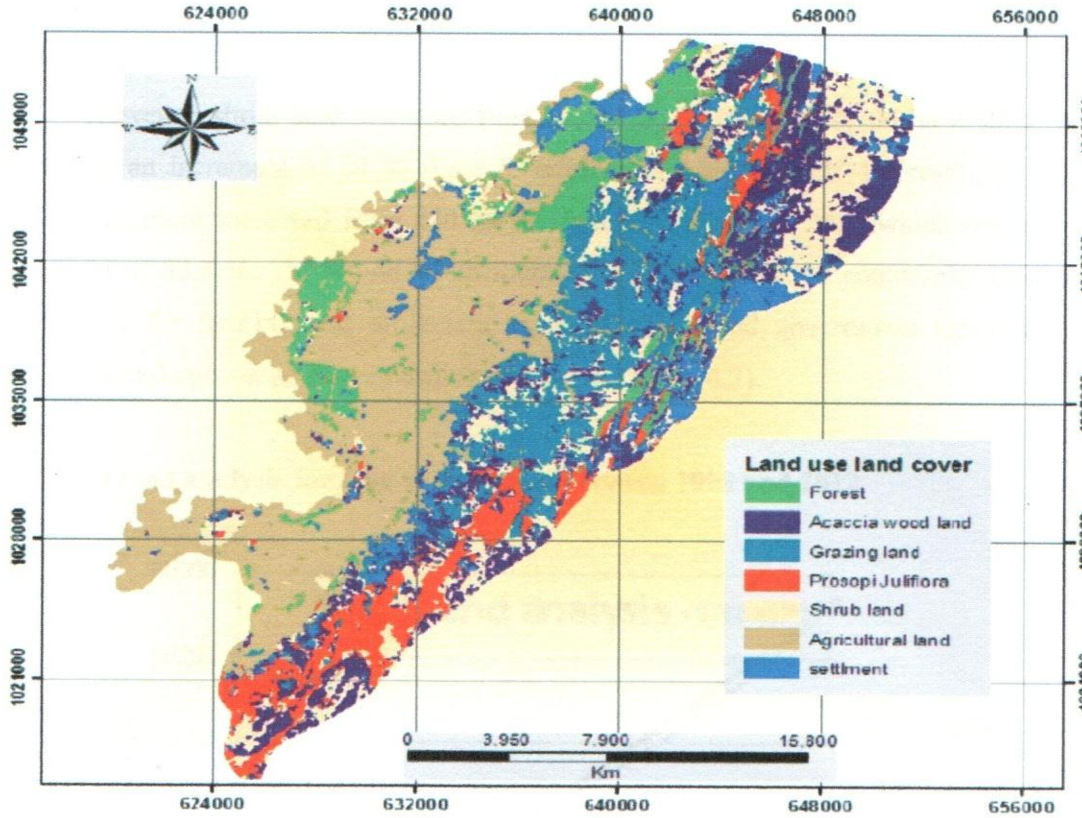


Plate 4.2: Satellite Imagery of the land use/ land cover map of the study area in 2012
Source DRSRS, 2012

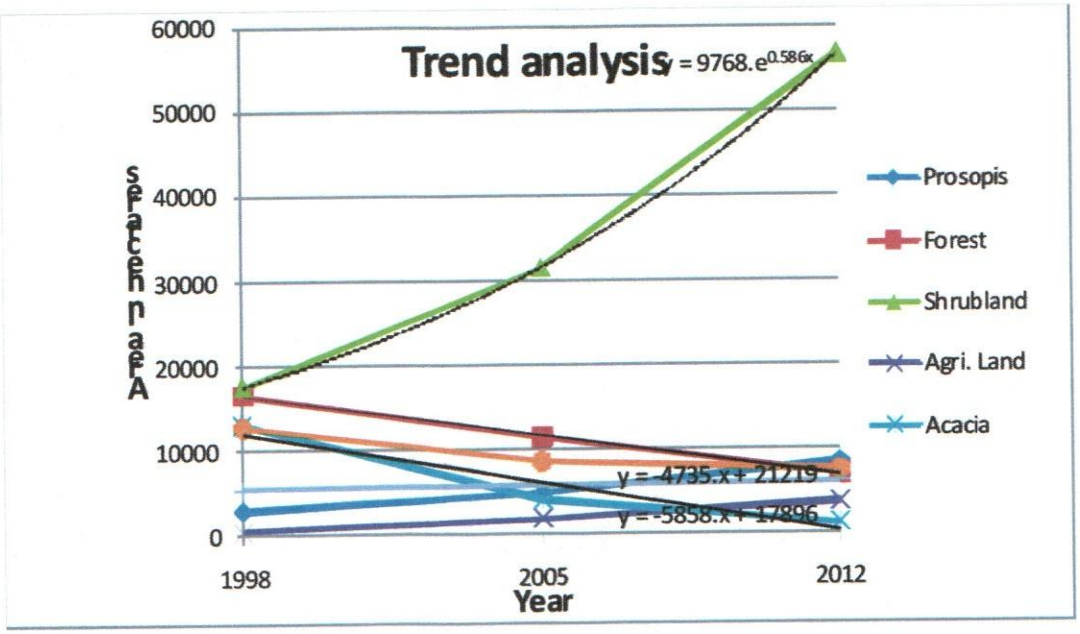
It may also be observed from the satellite image of 2012 (Plate 4.2) and the change detection matrix (Table 4.5) that forest cover had declined from an initial cover of 16,572 ha in 1998 to 7101 ha in 2012; this represents a decline rate of 57.1% which implies that the riverine forests are being lost to *P. juliflora* invasion at a fast rate.

Similarly acacia woodlots declined from an initial land cover of 13,045 ha in 1998 to a megre 1328 ha in 2012, which indicates a dramatic decline rate of 89.8%. This dramatic decline in acacia woodlots could be attributed to the ecological advantage of *P. juliflora* as it has allelopathic effects inhibiting growth of other species around it (Baumer 1990; Hulme 2012). Grazing land also declined from 12,749 ha in 1998 to 7609 ha in 2012, which represents a decline rate of 40.3%. Both livestock and wild animals feed on the pods from *P. juliflora* but are unable to digest the seeds which are only scarified and past through the nutrient rich dung which are spread in the grazing fields hence livestock act as dispersal agents. Floods run off and rivers wash the seeds downstream spreading the seeds further.

The observed decline in acacia woodlots and pastureland is a serious concern to the respondents as it has serious implications to their pastoral way of live. They depend on beekeeping from acacia woodlots, firewood from acacia woodlots and pasture for their livestock.

However, shrub land increased from 17,556 ha in 1998 to 56,704 ha in 2012 which represents an increment of 69 % since *P. juliflora* is a shrub itself. Interestingly the area under agriculture increased from 440 ha in 1998 to 3845 ha in 2012 which represents an increment of 88.5 %. This could be attributed to the efforts by the community to open up more areas for farming and settlement as more NGOs and government agencies create awareness and encourage maize farming in the area (Table 4.2).

Fig.4.2: Trend analysis for land use changes between 1998 and 2012



Source: Survey Data, 2012

From the trend analysis (figure 4.2) it may be observed that *P. juliflora* is invading at a linear function Y = 2824X - 166.6 whereas forests are declining at a linear function of Y = -4735X + 21219

Shrub land is increasing at a linear function of Y = 19574X - 3876 or an exponential function of $Y = 9768e^{0.586X}$

Acacia woodlots are declining at a linear function of Y = -5858X + 17896

In areas where the invasion was intense, some of the local people have vacated their homesteads (Plate 4.5). The combined lack of local knowledge on how people could best manage and use this tree, and of *P. juliflora* on communal lands where people have little or no responsibility to control its spread, have helped this rather invasive *P. juliflora* to first get a foothold, and then invade (Essa, 2006).

Plate 4.3: *P. juliflora* encroaching onto homesteads

Source; Researcher, 2009

Table 4.5: Dynamics of *P. juliflora* invasion

Change in land use cover	**1998-2012 Area km²**	**Change in land use cover**	**1998-2012 Area km²**	**Net change Area km²**
Grazing land to *P. juliflora*	711	*P. juliflora* to grazing land	124	-587
Dense acacia to *P. juliflora*	109	*P. juliflora* to Dense acacia	76	-33
Shrub land to *P. juliflora*	12	*P. juliflora* to shrub land	125	113
Settlement to *P. juliflora*	51	*P. juliflora* to settlement	181	130
Forest to *P. juliflora*	354	*P. juliflora* to forest land	511	157
Agricultural land to *P. juliflora*	771	*P. juliflora* to agricultural land	995	224
TOTAL	2008		2012	

Source: DRSRS, 2012

Table 4.5 shows the dynamics of *P. juliflora* invasion and changes caused to other land uses. The net change of grazing land lost to *P. juliflora* is 587 km^2 and acacia is 33 km^2 Overall, 61.8% of the entire land has been lost to *P. juliflora* invasion between 1998 and 2012. *P. juliflora* has invaded almost all land use types in the study area although the extent and severity of invasion varies from one land use type to another. The plant has highly encroached on Acacia woodlands. This is possibly because *P. juliflora* has allelopathic effects and coppices heavily from a single stem cut down for fire wood and charcoal. Pastoral livelihoods rely a lot on Acacia woodlands for honey production, fodder and firewood hence this invasion has impacts which need mitigation. Uncontrolled cutting down of *P. juliflora* could also have encouraged the invasion of the plant through coppicing (Lenacuru, 2006).

Table 4.6: Change detection matrix between 1998 and 2012

Land use/land cover classes	Land cover	2012 land use/ land cover classes(km^2) *P. juliflora*	Forest	Shrub land	Agricultural land	Acacia	Grazing land	Settlements	Total
1998 Land use/ land cover classes (km^2)	*P. juliflora*	66							71.6
	Forest	-49.2	-57.1						-79.4
	Shrub land	11.4	-64.3	69					26.8
	Agricultural land	16.3	-187.9	327.5	-88.5				496.8
	Acacia	-19.1	125.6	-55.4	-70.0	-89.8			-76.2
	Grazing land	-42.9	10.4	-10.3	-19.4	-22.8	-40.3		-97.1
	Settlements	-49.9	-39.9	21.0	-27.9	-11.6	-12.5	7.2	-62.6
	Total	-61.8	-186.3	362.5	205.8	-124.2	-52.8	7.2	279.9

4.3.1 Density of *P. juliflora*

Density of *P. juliflora* was used to show distribution of the plant in various land uses. Density was determined using the number of coppices per stool in each type of land use (Table 4.7). The number of coppices of *P. juliflora* determines the density of the plant per given area. It was determined that there were significant differences in the number of coppice in each of the land use (One-Way ANOVA $P < 0.05$). Coppicing was highest in acacia woodlands followed by grazing land, but was least in the settled areas. This could be attributed to minimum disturbance in acacia woodlands and the allelopathic effects of *P. juliflora*. The mean number of coppices was 4.4 ± 0.15 which is almost similar to findings by Abiyot and Getachew (2006). Therefore, this suggests that stumping of *P. juliflora* can increase the number of coppices per stool which then increases the density of *P. juliflora* per given area.

Table 4.7: The mean number of coppices per stool in each land use/land cover types

Land use/land cover types	N	Minimum	Maximum	Mean ± SEM
Agricultural land	35	4	21	14.52 ± 4.21
Settlement	44	3	13	9.11 ± 1.33
Shrub land	36	4	29	21.2 ± 4.55
Grazing land	42	5	25	23.5 ± 3.89
Acacia Woodland	39	4	42	37.9 ± 5.77
ANOVA				
F-value				18.55
P-value				0.004

Source: Survey Data, 2009

The densities of *P. juliflora* in different land uses were computed by counting the total number of coppices found in each plot and the average converted to hectares. It was observed that the density of *P. juliflora* was higher in Acacia woodlands (2774 stems/ha) than in riverine forests which had 644 stems/ha of *P. juliflora*. The density was lowest in the settled areas at 640 stems/ha (Figure 4.3). These findings suggest the fact that cutting down of *P. juliflora* above the ground increases the number of coppices which increases the density of the plant.

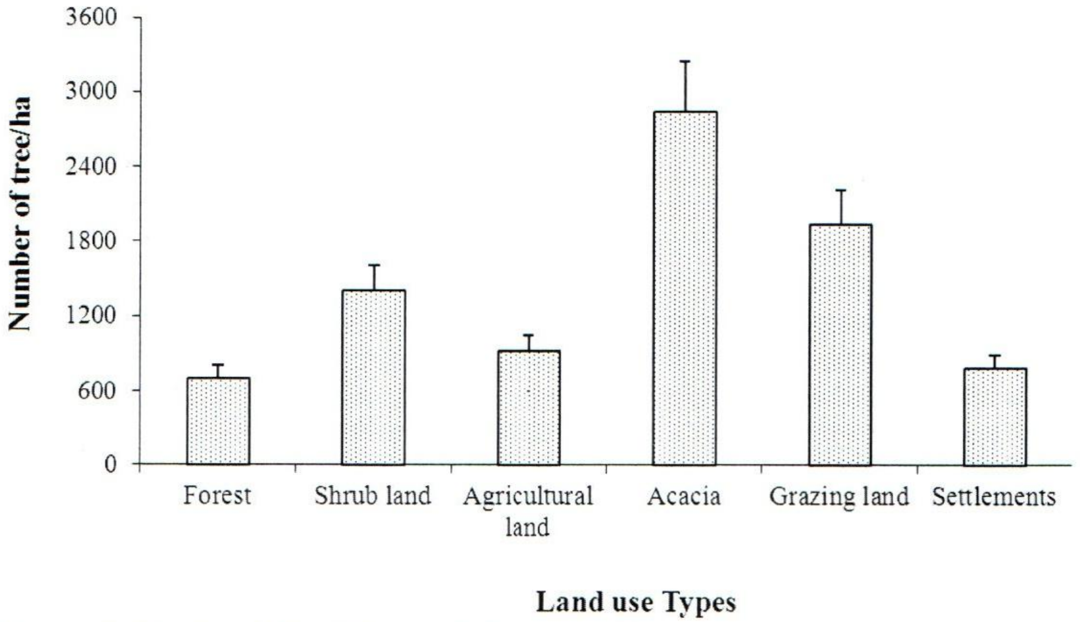


Figure 4.3: Density of P. juliflora in different land use types

Source: Survey Data, 2009

4.4: Impacts of *P. juliflora* on the ecology of Salabani.

P. juliflora is a domineering colonizer with allelopathic effects. It exudes chemicals that suppress growth of other plants around them, negatively impacting on biodiversity (Baumer, 1990; Coppen, 1995). In the study area, residents were able to identify some of the native species of socio- economic importance that were common in the area but have since been replaced due to the invasion of *P. juliflora* which is allelopathic. These were traditional vegetables, fruits, trees, and shrubs as indicated in Table 4.8. Some of these shrubs were important for browsing goats like *Balanites aegyptiaca* and some were used as traditional vegetables such as *Amaranthus hybridus*. It may be observed that *P. juliflora* is now invading into Lake Bogoria Nature Reserve and because of its invasive potential, it could be a threat to the biodiversity of the game reserve, an important Ramsar site in Kenya. If the invasion is not addressed, the tourism potential, revenue collection and sustainable use of Lake Bogoria game reserve, could be jeopardized.

Table 4.8: Species emerging or disappearing

Type	Emerging Species	Disappearing Species
Traditional Vegetables	-	*Amaranthus hybridus, Amaranthus spinosus solanum incunum, Achyranthes aspera (*devils horse weep)
Trees	-	All Acacia spp., sycamore spp., *Brussilica lowei*, Typha spp.., Cyperus spp.
Shrubs	Cactus	*Lantana camara, Myosotis* spp.(Forget me not), *Salvadora persica (Sokotei) Commelina benghalensis (Ekaitetea) Panicum maximum (Orpalakai) Cynodon plectostachyus (Emurua) Boscia spp. Balanites aegyptiaca*
Insects	Tsetse flies, mosquitoes	Houseflies
Arachnids	Spiders	-
Reptiles	Snakes	-
Birds	Red eyed fishers love bird (parrot) Sulphur breasted bush shrike Pearl spotted Omelet, Pelicans, Cormorants Kingfishers Hammer Cops weavers, Herons Egret Guinea fowls, Eagles and over 500 migratory bird species around Lake Baringo	-
Mammals	*Rhynchotragus kirki* (Dikdik) *Epomophorus wahlbergi* (bats) and the ant bears	-

Source: Survey Data, 2009

P. juliflora has replaced some macrophytes which occupy the lake ecotone on the water land interface of Lake Bogoria like Cyperus species yet *P. juliflora* does not have the filtration effect of the Cyperus species it replaces. This has affected the water quality of Lake Baringo due to siltation.

P. juliflora has replaced wild vegetables and fruits which were a source of food during drought season as a coping mechanism for the Ilchamus. This formidable invader has also affected native tree and shrub species like those of Acacia spp., sycamore spp., *Brussilica lowei*, and *Typha* spp. The loss of biodiversity is consistent with the findings of other scientists (Huston, 1993; Choge 2007). They note that invasion of *P. juliflora* alters vegetation structure and general ecology of the dry lands which can cause loss of endemic species of both flora and fauna. Competition for water between *P. juliflora* and native species is very high due to their rooting systems and invasiveness (Harding and Bate 1991). This could also affect competition for nutrients. This competition is made possible due to the allelopathic effects of *P. juliflora* (Baumer, 1990 and Coppen, 1995).

However, the thorny thickets of *P. juliflora* have offered protection to wild animals from poachers since it is difficult to penetrate the thorny bushes hence emergence of *Rhynchotragus kirki* (dikdiks). Spiders have proliferated on the shrubs as evident from the cobwebs. These spiders feed on common houseflies hence checking their population. This is because most are easily captured in the cobwebs and fed on by the spiders.

It may also be observed that *P. juliflora* has influenced emergence of mosquitoes and tsetse flies which are now abundant in the region .This might have an effect on the health of human beings and livestock. *P. juliflora* has also provided a nesting ground for birds, which can now be found in abundance especially around Lake Baringo. There are over 500 bird species around the lake attributed to *P. juliflora* bushes though they are migratory in nature. Birds have increased in the area due to the evergreen habitat. New species have emerged namely: the red eyed fishers love bird a small member of the Parrot family with a short hairy tail and bright green yellow plumes around the chest, Sulphur breasted bush shrike with speckles of grey on the nape, and the Pearl spotted omelet a rare bird with white brown and yellowish frills, Pelicans, Cormorants, Kingfishers, and Hammer cops.

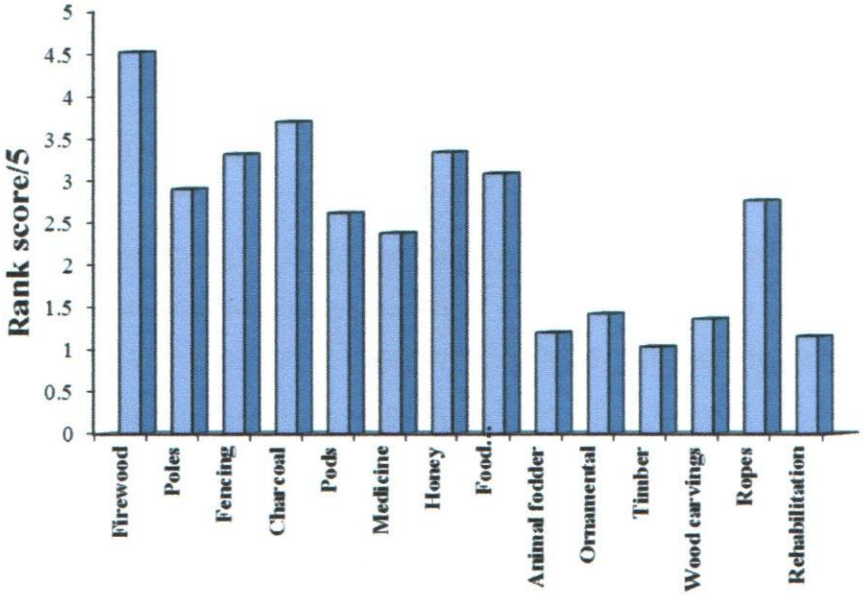
4.5: Comparison of costs and benefits of *P. juliflora*.

The second objective of this study was to determine costs and benefits associated with growth and utilization of *P. Juliflora* in Salabani Location. Based on observations and responses from the local community, *P. juliflora* was harvested and the products utilised or sold for economic gains in Salabani Location. It was observed that the main uses of *P. juliflora* in Salabani were for charcoal production, firewood, building and fencing poles. This section presents the evidence on the costs and benefits of *P. juliflora* by expressing the impacts in monetary terms. However, some environmental costs and benefits are intangible hence difficult to express in monetary terms, and were therefore not considered in this study.

4.5.1 Economic benefits

The relative importance of the uses of *P. juliflora* was evaluated using Likert score as shown in Figure 4.4. Based on the results, firewood had the highest rank score (4.52) followed by charcoal (3.7) and fencing (3.3) while the least ranked use of *P. juliflora* were: for timber (1.035), rehabilitation (1.16), fodder (1.21) and ornamental (1.42).

Figure 4.4 Rank score of the relative importance of various uses of P. juliflora in Salabani location



Source: Survey Data, 2009

Lack of awareness and knowledge to extract the exudates from the plant for its medicinal value and the crooked nature of the plant for use as timber has limited its uses to firewood charcoal and poles. Pods are also collected for fodder. The least mentioned uses of the plant are ornamental due to thorns and woodcarving since the Ilchamus are not woodcarvers. In India the plant extract is used to treat eye infections, stomach disorder, skin ailments and superficial wounds (Patel 1986). The plant is very important for live and dead fencing around the villages and farm lands in the study area (Kanzaria and Varshney, 1998). It has helped to keep away wild game which used to destroy crops especially wild pigs and hippos from Lake Baringo.

Table 4.9: Economic benefits of *P. juliflora* per household/year in Salabani

Economic use	Unit	Quantity	KES. (Per year)
Firewood	Back loads	250	5,000
Poles	Numbers	120	4,800
Fencing	Numbers	100	3,600
Charcoal	Sacks	240	120,000
Fodder	Kg	600	12,000
Medicine	Kg	0	0
Honey	Litres	240	24,000
Food	Kg	0	0
Timber	Numbers	0	0
Wood carvings	Numbers	0	0
Ropes	Meters	0	0
Total			169,400

Source: Survey Data, 2009

P. juliflora is a highly flowering evergreen plant with bright yellow flowers that easily attract bees hence increased honey production in Salabani. Farmers use both local beehives from logs and the improved Lungstroth and KTB beehives made by Kerio Valley Development Authority (KVDA) to produce honey. 240 litres of honey is produced per household per year in Salabani.

It was also observed that *P. juliflora* has high quality fuel wood with a high calorific value of 4.2 Kcal/gram to 4.8 Kcal/gram. 16 logs of green wood produced 6 bags of charcoal using the traditional earth kilns within 3 days. Improved Casamance charcoal kiln with improved carbonization control produces 8 bags, carbonizing in 3 days giving a charcoal recovery of 28-30% (Choge, 2002).

Records from KFS Marigat office indicate that on average 50 movement permits are issued for *P. juliflora* charcoal per month with each lorry carrying 100bags. This translates to 60,000 bags of charcoal per annum from Marigat. The retail price of charcoal in Marigat is KES 500 per bag. Hence annually *P. juliflora* charcoal produced in Salabani is estimated at KES 30 million.

Women respondents noted that they have access to plenty of firewood, previously a scarce resource. This has reduced the time and distances they used to walk in search of firewood. Desert storms of the early 1980s are also rare because of the positive influence of the trees in controlling such storms.

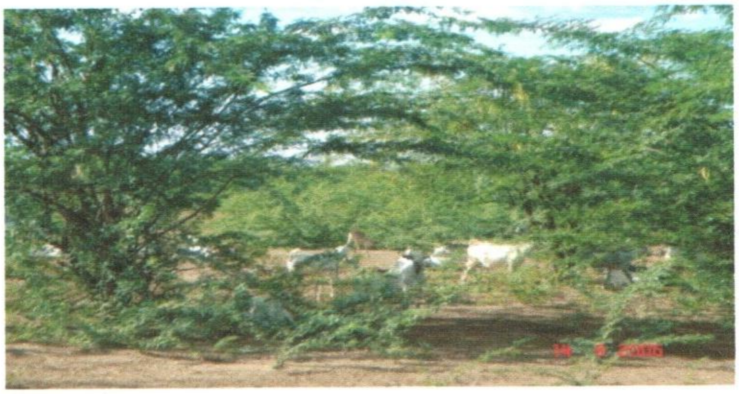
On average each household in Salabani location uses 250 backloads of firewood per annum costing KES 5,000 which translates to KES 10 million for the total population of 2,000 households. Each household uses 120 poles per annum costing KES 4, 800 which translates to KES 9.6 million for Salabani Location. The local community produces 240 bags of charcoal per year per household which costs KES 120,000 which translates to KES 240 million worth of charcoal from Salabani location every year. Each household produces 240 litres of honey per annum under *P. juliflora* costing KES 24,000 which translates to KES 48 million. Therefore, the total economic benefits accruing from products associated with *P. juliflora* is worth KES 169,400 per household or KES 338.8 million for the entire Salabani location annually. See the various uses of *P. juliflora* in plates 4.4 – 4.6.

Plate 4.4 Charcoal production using the improved Casamance charcoal kiln

Source: Author, 2006

.

Plate 4.5 Goats browsing on *P. juliflora*



Source: Author, 2006

.

Plate 4.6 Poles from *P. juliflora*

Source: Author, 2006

4.5.2 Economic costs of *P. juliflora*

Besides the benefits, this study also investigated the negative aspects associated with *P. juliflora.* The problems associated with *P. juliflora* invasion varied considerably between highly invaded areas and less invaded areas. In densely invaded areas, respondents noted that the most severe problems were related to injuries to man and livestock by the thorns of *P. juliflora.* This increased the cost of treatment. In some cases, goats lost their teeth probably due to high sugar content of the plants' pods hence they starve to death. Thorns also pierce the hooves of animals limiting their movement and lowering quality of hides and skins. by 39% of the respondents reported that *P. juliflora* led to a reduction of grazing land , 45% reported that the thorny thickets prevent animal movement , 10% reported that it blocks infrastructure, while 8% reported that it hosts crop pests (Tables 4.10 and 4.11).

Table 4.10: Economic impacts of *P. juliflora*

Economic use	Frequency Reported Cases	Percent
Decreased woodlands	21	10.5
Injury to animals	65	32.5
Reduced biodiversity	44	22
Reduced crop production	77	38.5
Decreased grazing land	78	39
Restricted movement	90	45
Blocked infrastructure	20	10
Crop pests	16	8
Thorns puncture tyres	194	97
Host predators	150	75

Source: Survey data. 2009

P. juliflora pods have high sugar content which enhances activity of rumen bacterial cellulase that causes teeth decay in livestock leading to high mortality cases in Salabani (Plate 4.9).

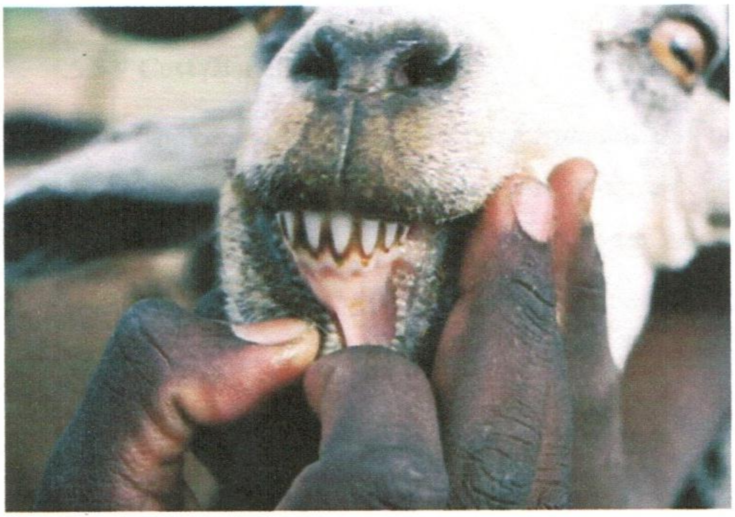


Plate 4.7: Goat with *P. juliflora* stuck in the teeth
Source: Researcher; 2009

Table 4.11: Economic Losses incurred per household per year due to *P. juliflora*

Impact	Number per year	Estimated costs KES
Cattle death	2	40,000
Goat deaths	8	24,000
Livestock treatments	15	15,000
Cost of clearing *P. juliflora*	600 Man hours	30,000
Repair of bicycle tyre punctures	150	3,000
Cost of treatment (human health)	4	16,000
Total Economic loss		128,000

Source: Survey Data, 2009

The economic costs due to injury by thorns of the plant, punctures to bicycle tyres death of livestock, are estimated at KES 128,000 per household per annum. The weed has also blocked access routes to watering points on Lake Baringo and River Endao hence residents have to move for longer distances in search of water. Routes blocked include the one leading to Salabani primary and Salabani secondary schools, the only schools in the area as well as the route to Marigat town. As a result of this invasion, some respondents have relocated to other areas.

4.5.3 Cost /Benefit Analysis

The economic benefits accruing from utilizing products of *P. juliflora* amount to KES 169,400 per household per year whereas the corresponding economic costs or losses amount to KES 128,000 per household per year. These values are then discounted to get the net present value of *P. Juliflora.*

$$\text{Present value (Pv)} = \frac{P_t}{(1+r)^t}$$

Where

PV is the Present value, r is the Interest rate (discount rate) 10%, Pt is the Value in future time t

Present value of Benefits (PV)	169,400/1.9487171	= 86,928.98
Present value of costs	(128,000/1.9487171)	= 65,684.24
Net Present Value (NPV)	(86, 928.98 – 65,684.24)	= 21,244.74

When NPV is greater than zero (NPV > 0) the project is viable for implementation and in this case NPV is 21, 244.75 hence utilization of the weed is a viable enterprise.

$$\textbf{NPV} = \frac{\text{sum of benefits - sum of costs}}{(1+r)^t} = \frac{169{,}400 - 128{,}000}{1.9487171} = 21{,}244.75$$

Benefit/Cost/ Ratio (BCR)

$$\text{BCR} = \frac{\text{NPV(Benefits)}}{\text{NPV (Costs)}} = \frac{65{,}684.24}{21{,}244.74} = 3.09178837$$

When BCR is greater than one the project is economical and should be accepted and for this case BCR is 3 hence maintaining *P. juliflora* is beneficial to the community.
Internal rate of return (IRR) = 23.23% which is greater than the Discount rate 10% hence maintaining *P. juliflora* is economically acceptable.

Hence, based on the above Cost/ Benefit analysis, the introduction and spread of *P. juliflora* is profitable and acceptable for the following reasons: the present value of benefits exceeds present value of costs, the Net Present Value (NPV) is greater than zero, the benefit/cost ratio (BCR) is greater than one and the internal rate of return (IRR) is greater than the discount rate.

4.6 Relationship between soil characteristics and the spread of *P. juliflora*

The study also determined the relationship between soil characteristics and spread of *P. juliflora* in the study area (objective 3). This objective was investigated in view of curiosity surrounding the rapid invasion of *P. juliflora* in the study area; the factors influencing such rapid growth of the plant. Indeed it was speculated that the major driver of this invasion may have been the nature and characteristics of the soils in the study area.

Table 4.12 shows the soil characteristics and how they vary in different densities of invasion of *P. juliflora* from high density to zero density. Table 4.13 shows a statistical analysis of soil nutrients under different densities of *P. juliflora* using ANOVA. The raw data is presented in Appendix IV.

Table 4.12: Soil characteristics in varying stand densities of *P. juliflora* in Salabani Location.

	***P. juliflora* density**		
Soil characteristics	**None**	**Low**	**High**
pH	7.73 ± 0.14	7.59 ± 0.15	7.4 ± 0.32
E.C	0.11 ± 0.02	0.14 ± 0.02	0.16 ± 0.02
C	0.12 ± 0.04	0.36 ± 0.23	1.5 ± 0.39
Organic matter	0.21 ± 0.004	0.62 ± 0.39	2.43 ± 0.53
TN	0.05 ± 0.01	0.23 ± 0.07	0.89 ± 0.12
TP(ppm)	2.95 ± 0.05	28.63 ± 12.24	38.96 ± 5.67
K(ppm)	232 ± 12.5	343.0 ± 79.7	344.3 ± 56.4
Na(ppm)	74.5 ± 8.51	161.2 ± 44.5	258.3 ± 9.24
Ca(ppm)	2951.5 ± 101.5	4614.3 ± 398.1	4488 ± 306.7

Source: Survey Data, 2009

It may be observed from table 4.12 that soils under high *P. juliflora* density stands had significantly lower pH value which suggests that they are more acidic than soils in the open with no *P. juliflora* cover. The slight acidity of the soils under high density *P. juliflora* stands could be attributed to leaches and exudates from the litter that falls and rooting of *P.*

juliflora. The findings of this study are in agreement with those of Bhatia *et.al.* (1998) who observed a significant reduction in soil pH under the canopies of *P. juliflora.*

It was also observed that soil nutrients and electrical conductivity increased from low density stands to high density stands of *P. juliflora.* The high electrical conductivity could be attributed to the presence of cations. Organic carbon content and organic matter was significantly high under high density *P. juliflora* stands than in the open areas. The accumulation of organic carbon and organic matter below the tree canopies may be partly due to litter fall and reduced leaching under the tree canopy. Birds and other animals which have found a habitat under *P. juliflora* stands could also be responsible for the higher organic carbon and phosphorous observed and reduced leaching under the tree canopies (Felker 2003). Soils under high *P. juliflora* density had seventeen times total nitrogen content than soils without *P. juliflora* and had more than four times nitrogen than soils under low *P. juliflora* density.

Available phosphorus was significantly higher in the areas of high *P. juliflora* density than areas with low density or none. The high available phosphorus content under *P. juliflora* could be attributed to biological processes that are continuously taking place between the Rhizobium bacteria and the tree roots, as *P. juliflora* is leguminous. The phosphorous concentration under *P. juliflora* canopies could also be attributed to pumping of soluble phosphorous from deeper soil layers (Geesing *et.al.* 2000). Legumes have been found to be more efficient in obtaining phosphorous from insoluble sources due to the increased cation exchange capacity of their rooting systems that lowers the calcium activity of the soil solution facilitating the release of phosphorous from insoluble Ca-P compounds (Geesing *et.al.* 2000). The results of this study are consistent with those of Young (1989) who also observed high phosphorus under the tree canopy and attributed it to biological nitrogen fixation by Rhizobium bacteria. Frias - Hernandez, *et.al.* (1999) found phosphorous to be two times greater under *P. juliflora* than in the open. Gadzia and Ludwig (2009) found soils under *P. juliflora* to have higher concentrations of calcium, magnesium, and potassium than those in open areas in southern New Mexico. Klemmedson and Tiedemann (1986) also found more potassium in soils under *P. juliflora* and linked it to higher electrical conductivity.

The study therefore concludes that it is not the soil characteristics that influence the invasion of *P. juliflora,* rather it is the plant itself that enriches the soil nutrients, thus lowering the soil pH and increasing cation exchange capacity. These then contribute to invasiveness of the plant. The plant fixes its own nitrogen from the Rhizobium bacteria in its nodules whereas leaches and exudates from litter fall increase acidity and organic matter. The deep rooting system is also thoughtto pump nutrients from deeper soil layers.

Table 4.13: ANOVA table showing differences in soil characteristics in areas with different *P. juliflora* densities

		Sum of Squares	df	Mean Square	F	P-value
pH * *P. juliflora.*_density	Between Groups	2.077	2	1.0385	2.642	0.008
	Within Groups	0.786	5	0.393		
	Total	0.863	7			
E.C * *P. juliflora.*_density	Between Groups	0.311	2	0.1555	51.833	0.003
	Within Groups	0.006	5	0.003		
	Total	0.01	7			
C * *P. juliflora* _density	Between Groups	2.934	2	1.467	2.360	0.048
	Within Groups	1.243	5	0.6215		
	Total	4.177	7			
Organicmatter**P. juliflora.*_density	Between Groups	7.551	2	3.7755	2.862	0.034
	Within Groups	2.638	5	1.319		
	Total	10.189	7			
P (ppm) * *P. juliflora.*_density	Between Groups	2587.75	2	1293.875	2.370	0.106
	Within Groups	1091.958	5	545.979		
	Total	2679.709	7			
K(ppm) * *P. juliflora.*_density	Between Groups	38706.833	2	19353.4165	2.891	0.005
	Within Groups	13388.667	5	6694.3335		
	Total	82095.5	7			
Na (ppm) * *P. juliflora.*_density	Between Groups	51615.708	2	25807.854	4.109	0.026
	Within Groups	12561.167	5	6280.5835		
	Total	54176.875	7			
Ca (ppm) * *P. juliflora.*_density	Between Groups	4862762.708	2	2431381.354	3.166	0.043
	Within Groups	1535997.167	5	767998.5835		
	Total	5398759.875	7			

4.7 Coping mechanism to spread of *P. juliflora* as practised by the local people.

Besides the three main objectives, this study also examined the coping mechanisms used by the local community to deal with the spread of *P. juliflora.*

The Government of Kenya and FAO through KEFRI trained the residents on how to manage the invasive species. They formed farmers' field schools (FFS) for training, creating awareness and capacity building. The local people have since adopted some coping mechanisms to control further spread of *P. juliflora*. From the study it was reported that 49% of the respondents burn the stands, 44% use it as a raw material for charcoal production, 28 % mechanically uproot the seedlings, 22% prune the weed while 12.5 % collect pods for sale to animal feed manufacturers. The farmers do not use any chemical or biological control methods. Chemical control is expensive and beyond their means.

Table 4.14: Methods used to control further spread of *P. juliflora*

Method	Type	Frequency	Percent
Mechanical(uprooting)	Management	56	28.0
Burning	Management	98	49.0
Pod collection	Utilization	25	12.5
Charcoal making	Utilization	88	44.0
Chemical	Control	0	0
Thinning	Management	14	7.0
Pruning	Management	44	22.0

Source: Survey Data, 2009

Some respondents use dry cow dung to burn the stems. Cow dung burns for a longer time hence effective. Some respondents have migrated to other areas. Management options practiced are uprooting, burning, thinning and pruning whereas utilization involves charcoal production and pod collection. Experiences from America, Asia and Australia indicate that eradication of *P. juliflora* entirely is difficult. However biological control is gradually gaining prominence in America and South Africa for its cost effectiveness, ecological and environmental compatibility and no disturbance to the soil (Zimmerman 1991; Hildegard, 2002).

CHAPTER FIVE

SUMMARY OF KEY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, a summary of key findings, conclusions and recommendations are made based on the three specific objectives of the study. These were: To determine extent of invasion of *P. juliflora* and the impacts on land use and ecology; Second objective was to determine costs and benefits of *P. juliflora* and third objective was to determine relationships between soil characteristics and the spread of *P. juliflora* in Salabani Location.

5.2 Summary of key findings

The study established that by 1998 *P. juliflora* had spread to a total acreage of 2,906 ha only. However, by 2012, the weed had invaded a total acreage of 8,555ha. The invasion of the weed has significantly changed land use of the study area especially forests, Acacia woodlots and pasture land. It is increasing at a linear function $Y = 2824X - 166.6$. The plant has replaced traditional vegetables, fruits and shrubs and is now invading into Lake Bogoria nature reserve.

The study also established that it is economically viable to utilise the invasive weed since the Net Present Value (NPV) is greater than zero while the Cost/ benefit ratio (CBR) is greater than one.

In addition, soil nutrients, acidity and CEC increase under dense *P. juliflora* stands than in the open areas.

5.3 Conclusions

The study concludes that *P. juliflora* is spreading at a very high rate and this is a concern to all stakeholders. The invasion has affected the way of live of pastoralists as it has reduced pasture land and acacia woodlots. Encroachment of *P. juliflora* is becoming a threat to the ecosystem of Lake Bogoria nature reserve which will affect its sustainability. The tree out competes other plant species but enriches the soil nutrients as it spreads.

However, the economic benefits outweigh the economic losses since charcoal production is a multimillion enterprise though the residents have underutilized the tree. Pastoralists rely on their livestock than any other source of income hence they perceive the weed negatively.

In view of the many potential uses of *P. juliflora* all efforts should be made to exploit these products and services.

5.4 Recommendations

The study makes the following recommendations based on the study objectives, key findings and conclusion.

5.4.1 Policy

The study recommends that the government of Kenya should undertake the following: enhance commercial utilization of the *P. juliflora* tree through: charcoal production, fast track the establishment of a plant to generate steam energy which has already been approved by NEMA; remove trade barriers in charcoal production and transportation by issuing movement permits for *P. juliflora* charcoal. In addition, government should adjudicate the land to enable individuals own the resource which they can then sale to private entrepreneurs. The government should introduce non-invasive and thorn less *Prosopis chilensis* alongside commercial utilization of *P. juliflora.* The government should create awareness among communities and private entrepreneurs about other potential uses of the plant like: processing of animal feeds from the pods of the tree, wax for pharmaceutical companies and medicinal value.

The local community should enhance utilization of *P. juliflora* through charcoal production and increase acreage under pasture by planting *Syngras cilliaris* grass which has been introduced in the study area by RAE trust a local NGO. The local community should sale firewood to the Aloe factory at Koriema in Baringo as a source of income. The community should stop burning *P. juliflora* as it encourages re-sprouting from damaged stems, scarifies the dormant seeds and removes all valuable native plants from the ground. Moreover, it also releases carbon dioxide which contributes to global warming.

KWS and Baringo County government should uproot seedlings of *P. juliflora* which are encroaching into Lake Bogoria nature reserve before they spread further.

5.4.2 Areas for Further Research

Literature review suggests several other benefits associated with *P. juliflora.* One such benefit this research has not examined is the medicinal value of *P. juliflora*. It is therefore recommended that a study be done to verify claims emerging from countries like Guatemala and India on the efficacy of treating diseases like eye infection, stomachache, skin ailments, wounds, sexually transmitted diseases, sore throat and common colds, based on *P. juliflora.*

The study also recommends that an EIA / EA should be done for other areas where this plant species has been introduced in Kenya.

It is also recommended that research be carried out on the possibility of replacing *P. Juliflora* with *P. chilensis* ,which is not invasive and spineless.

Lastly, further research should be done to verify claims that *P. juliflora* utilizes a lot of water through its deep rooting system and to facilitate its fast growth, which has the potential to negatively affect the water table in ASALs.

REFERENCES

Abiyot, B. and Getachew, T: The *P. juliflora* dilemma, Impacts on dry land biodiversity and some controlling methods: *Journal of the Dry Lands*. **1(2)**: 2006.158-164.

Alan, A. and Barbara, F: Statistical Methods for social sciences. 2nd Edition: Dellan, USA 1986.

Alban, L., et.al.: Cloning of multipurpose trees of the *Prosopis juliflora/pallida* complex in Piura, Peru *Agroforestry Systems*. **54**: 2002.173–182

Barth, R. C. and J. O. Klemmedson: Amount and Distribution of dry matter Nitrogen and Organic carbon in Soil - plant systems of mesquite: Virginia. *Journal of range Management* **35**.1982.412-418

Baumer, M.: *The potential role of agroforestry in combating desertification and environmental degradation with special reference to Africa.* Wageningen, the Netherlands: CTA. 1990.

Becker, R. and Grosjean, O. K. K: A compositional study of pods of two varieties of mesquite (*P. glandulosa*, and *P. velutina*): *Journal of Agricultural and Food Chemistry*. **28**:2009. 22-25.

Bhatia, N. P., Adholeya, A. and Sharma, A.: Biomass production and changes in soil productivity during long-term cultivation of *P. juliflora* (Swartz) DC: Inoculated with VA mycorrhiza and *Rhizobium* spp. in semi-arid wasteland: *Biology and Fertility of Soils*. **26**:1998. 208-214.

Boardman, N.E: *Cost Benefit Analysis concepts and Practices*, (3rd edition): Upper Saddle River. New Jersey: Prentice Hall, 2006.

Burkart, A: A Monograph of the Genus *Prosopis* HYDRA, Coventry UK. . 2007. pp 162

CABI: *Forestry compendium global module,* CD-ROM. Wallingford, UK: CAB International. 2000.

Carter, J.O. *Acacia nilotica:* a tree legume out of control. Pages 338–351 in R. C. Gutteridge and H. M. Shelton (ed). *Forage tree legumes in tropical agriculture.* Wallingford, UK: CAB International. 1994. Online: http://www.fao.org/ag/AGP/AGPC/doc/Publicat/ Gutt-shel/x5556e0v.htm.

Catterson, T.: USAID Strategic integrated plan in the Sudan, 2003-2005 environmental threats and opportunities assessment: USAID/REDSO/NPC and the USAID Sudan Task Force. Washington, March 2003.

CBD: Convention on Biological Diversity. http://www.biodiv.org. 2001.

Chamberlain, J. R. and Pottinger, A. J.: Genetic improvement of *Calliandra calothyrsus.* Pages 250–257 in *Nitrogen fixing trees for acid soils: Workshop proceedings:* Morrilton, AR: Winrock International and Nitrogen Fixing Tree Association. 2006.

Choge S.K., *et.al. The Status and Impact of Prosopis spp. in Kenya*: KEFRI, Nairobi, Kenya. 2002. 59 pp

Choge, S.K., *et.al. Prosopis* Pods as human food, with special reference to Kenya: *Water SA* 33 (3): 2007.419-424.

Coppen, J. J. W.: *Gums, resins and latexes of plant origin.* Rome: Food and Agriculture Organization of the United Nations. 1995.

Crooks, J.A. Characterizing ecosystem-level consequences of biological invasions: the role of ecosystem engineers: *Oikos*. **97**: 2002.53–166.

Daechler, C. C. The taxonomic distribution of invasive angiosperm plants: ecological insights and comparison to agricultural weeds: *Biological Conservation*. **84:** 1998.167-180.

Dennill, G. B. *et.al.* Insect agents used for the biological control of Australian *Acacia* species and *Paraserianthes lophanth* in South Africa: *African Entomology Memoir.* **1**: 1999.45–54.

Durr, P. A: The biology, ecology and agroforestry potential of the rain tree: *Samanea saman* (Jacq.) Merr: *Agroforestry Systems.* **51**: 2001.223–237.

El Fadl, M.A. *Management of P. juliflora for use in agroforestry systems in the Sudan.* PhD: thesis, Department of Forest Ecology, University of Helsinki, Finland. 1997.

Esbenshade, H.W. A Tree Crop in Hawaii: International Tree Crop Journal. 1980

Essa, S., *et.al.*, Mapping dynamics of invasive *P. juliflora* in the Northern Emirates of the UAE: An application of Remote Sensing and GIS. 2006.

Felker, P. Management, Use and Control of *P. juliflora* in Yemen; Mission report, Project Number: TCP/YEM/0169 (A). 14 August 2003 (ed.)

Felker, P. *et.al.*, Salinity tolerance of the tree legume: Mesquite (*P. glandulosa* var. *torreyana*, *P. velutina* and *P. articulata*), algar robo (*P. chilensis*), Kiawe (*P. pallida*) and tamarugo (*P. tamarugo*) grown in sand culture on nitrogen-free media: *Plant and Soil*. **61**:2007. 311-317.

Frias-Hernandez, J.T., *et.al.* Soil characteristics in semiarid highlands of central Mexico as affected by mesquite trees (*P. laevigata*): *Arid Soil Research and Rehabilitation*. **13**:1999. 305-312.

Gadzia, J.G.S, and Ludwig, J.A. Mesquite age and size in relation to dunes and artifacts: The *Southwestern Naturalist*. **28**:2009. 89-94.

Geesing, D., *et.al.*: Management of introduced *P. juliflora* species: Can Economic Exploitation Control an Invasive Species? *Unasylva*: **217**: 2004. 36 - 44.

Geesing, D., Felker, P. and Bingham, R.L. Influences of mesquite (*P. glandulosa*) on soil nitrogen and carbon development: Implications for global carbon sequestration: *Journal of Arid Environments*. **46**: 2010.157-180.

GoK *District Development Plan Baringo*, Government printers, Nairobi, 2002.

GoK Environmental Management and Coordination Act (EMCA) Government printers, Nairobi, 1999

GoK *National Housing and Population census report*, Government printers, Nairobi, 2009

GoK *State of Environment Report 2006/2007*, Kenya: Government printers, Nairobi, 2006.

Gold, A. G. From wild pigs to foreign trees: oral histories of environmental change in Rajasthan. Pages 20–58 in S. T. Madsen (ed.) *State society and the environment in South Asia:* Richmond, VA: Curzon. 1999.

Harding, G.B. and Bate, G.C: The occurrence of invasive *Prosopis* species in the north-western Cape, South Africa. *South African Journal of Science*; **87**: 1991.188–192.

Haysom, K.A. and Murphy, S.T. The status of invasiveness of forest tree species outside their natural habitat: a global review and discussion paper. Forest Health and Biosecurity: Working Paper FBS/3E. Forestry Department, FAO; Rome, 2003

Hildegard, K: *The Potential for Biological Control of the South African weed.* Plant Protection Research Institute. Pretoria, South Africa, 2002

Houston, J.E.: Biological characteristics that foster invasion of *Prosopis juliflora. Illinois Woodland Ecology*, West publishing company, New York. **69:**1993. 233-249

Hulme, P.E. *Prosopis* invasion*: Implications for the biodiversity of Caatinga in Northeast Brazil:* Online: http://www.dur.ac.uk/Ecology/phrpro.htm. 2012

IUCN: An Approach to Assessing Biological Diversity; Gland Switzerland, 2004.

Jacoby, P. and Ansley, R. J. Mesquite: Classification, Distribution, Ecology, and Control. Oxford, UK. 1991.

Jadhav, R. N.: Kimothi, M.M. and Kandya, A. K. Grassland mapping monitoring of Banni, Kachchh (Gujarat) using remotely-sensed data. *International Journal of Remote Sensing*: **14**: 1993. 3093–3103.

Jhala, Y.V: Predation on blackbuck by wolves in Velavadar National Park, Gujarat, India. *Conservation Biology*: **7**: 1993. 874 – 881.

Kanzaria, M. K. and Varshney, A.K: *P. juliflora* – Its Uses in Tewari, J.C. *Prosopis* Species in the Arid and Semi-Arid Zone of India. *Prosopis Society of India: The Henry Doubleday Research Association*. Coventry, U.K. 1998.

Kathiresan, R. M: Effect of Global warming on Invasion of Alien plants in Asia. Annamalai University, India. 2008

Klemmedson, J.O., and. Tiedemann, A.R. Long-term effects of mesquite removal on soil characteristics: Nutrient availability; *Soil Science Society of America*; **50:**1986.

Klinken, R. D., and Campbell, S. D. The Biology of Australian Weeds: **37**. *Prosopis* species: *Plant Protection Quarterly*. **16**: 2–20. 2001

Kothari, C.R. *Research methodology: Methods and techniques*. Daryaganj, New Delhi: New Age International (P) Ltd. 2004.

Laxen, J: Is *P. juliflora* a curse or a blessing?- An ecological-economic analysis of an invasive alien tree species in Sudan. Tropical Forest Reports: University of Helsinki: Viikki Tropical Resources Institute, Sudan. 2007.

Lea, J: A Review of Literature on Charcoal in Haiti in Felker, P and Moss, J. (Ed) (1996): *P.*: Semi-arid Fuel wood and Forage Tree: Building Consensus for the Disenfranchised Center for Semi-Arid Forest Resources, Kingsville Texas, USA. 1996.

Lenacuru, C. I: Impacts of *Prosopis* species in Baringo district. *Proceedings of a workshop on integrated management of Prosopis species in Kenya*. pp. 41-47.2006.

Levine, J.M., et.al. Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society of London* B. **270**: 2003.775–781

MacArthur R.W. and E. O. Wilson: *The Theory of Island Biogeography*: Princeton University Press: Princeton, 1967.

Meyerhoff, E. Taking Stock: Changing livelihoods in an Agro-pastoral Community. Acts Press, Africa Centre for Technology Studies, Nairobi. 1991. PP 58.

McNeely, J.A., et.al. (ed). *A Global Strategy on Invasive Alien Species.* Gland, Switzerland: International Union for the Conservation of Nature and Natural Resources. 2011

Mugenda O.M and Mugenda, A.G. Research Methods: Quantitative and Qualitative approaches. Nairobi, Act Press. 1999.

Mwangi, E. and Swallow, B. Invasion of *P. juliflora* and local livelihoods: A Case study from the Lake Baringo area of Kenya; Working paper. No .2.World Agroforestry Centre. ICRAF, Working Paper No., 3. 2005.

Nabli, M. and J. B. Nugent; The New Institutional Economics and Its applicability to Development: *World Development* **17(9)**: 1989. 1333 - 1347.

Ndegwa, C; Fuelwood Afforestation and Extension in Baringo, Kenya: 6months report, April September, 1987. FAO – GCP / KEN/051 /. 2006.

Nilson, E.T. *et.al.*, Diurnal and Seasonal Water Relations of the Desert *P. juliflora*-glandulosa (honey mesquite) in Sonoran Desert, California; *Ecology* **64:** 1983. 1381 -1393.

Parker, H.W.; Mesquite Utilization*: Texas Technical University*, Lubbock, Texas, USA. 1999.

Pasiecznik N.M., *et.al.* The *P. juliflora – P. pallida* Complex: A Monograph. *HYDRA Coventry UK*. 2001.

Patel, K. J. (Ed): The Role of *Prosopis* In Water Land Development: Jivrajbhai Patel Agro-cores Centre, Surendrabag, and Gujarat, India. 1986. 476 - 480.

Perrings, C., *et.al.*, Biological invasion risks and the public good: an economic perspective. *Conservation Ecology* **6**(1): 1. http://www.consecol.org/vol6/iss1/art1. 2002.

Pimentel, D. *et.al.*: Environmental and economic costs of non-indigenous species in the United States. *BioScience*. 50(1): 2000.53-65

Raghubanshi, A.S. *et.al.*, Invasive alien species and Biodiversity in India: *Current Science*. **88**(4)**:** 1-12. 2005.

Richardson, D. M. et.al.: Plant invasions: the role of mutualisms. *Biological Reviews*. **75:** 2000. 65 – 93.

Sala, O.E., *et.al.*, Global biodiversity scenarios for the year 2100. *BioScience*. **287**:2006. 1770–1774

Saxena, S.K. and Venkateshwarlu, J. Mesquite: An Ideal Tree for Desert Reclamation and Fuel Wood Production. India Farming. **41.** 1991.PP 15 -21.

Shackleton, C.M. *et.al.*, Assessing the effects of invasive alien species on rural livelihoods: Case example and a framework from South Africa. *Human Ecology an Interdisciplinary Journal*; 12: 36-44. 2006.

Sharifi, M.R., Nilson, E.T., Virginia, R.A.*et.al.*, Phenological pattern of current season shoots in *P. juliflora- glandulosa* in the Sonoran desert of South California. *Flora*. **173**: 265-277. 2008.

Sharma, R. and Dakshini, K. M. M.; Integration of Plant and Soil Characteristics and the Ecological Success of two *Prosopis* species; *Plant Ecology*: 139: 63–69. 1998.

Silva, S.: *P. Juliflora* in Brazil in Habit, M.A. and Saavedra J.C. (ed.) (1990). *The Current State of Knowledge of P. juliflora*: FAO, Rome, Italy. 1990.

Sumanen, J. Production Costs and Feasibility of growing *Prosopis* in irrigated plantation in Bura, Kenya East Africa. Agriculture and Forestry Journal 58 PP 91-99.1983.

Talpada P.M. and Shukla P.C. Study on Sugar and Amino Acids Composition of *P. juliflora* Pods: *Gujarat Agricultural University Research Journal*. **14**(1): 32-35. 1988.

Tewari, D.D: Economics and Management of Non- Timber Forest Products: A Case Study of Gujarat, India. Oxford and IBH Publishing: New Delhi, Calcutta, India, 1998.

Tewari, J.C., *et.al.,* Managing *P. juliflora*: A Technical Manual, CAZRI, Jodhpur, India and HYDRA Coventry, U. K, 2000.

Tiver, F., *et.al.*: Low density of prickly acacia under sheep grazing in Queensland: *Journal of Range Management*. 54: 2001.382–389

Tiwari, J.K. and Rahmani, A .R. An army of mad trees: profile a tree that is changing the face of Kutch. *Down to Earth* 7:32–34. Online: http://www.oneworld.org/cse/ html/ dte /dte990415/dte_cross1.htm. 1999.

Van Wilgen, B.W., Le Maitre, D.C. and Cowling, R. M. Ecosystem services, efficiency, sustainability and equity: South Africa's working for Water programme. *Trends in ecology and Evolution*. **13**:1998. 378.

Veitch, C.R. and Clout, N. Human dimensions in the management of invasive species in New Zealand. In: McNeely, J.A. (Editor). 2001. *The Great Reshuffling: Human Dimensions of Invasive Alien Species*; IUCN, Gland, Switzerland and Cambridge, UK. 2001

Versfeld, D.B. and van Wilgen, B.W.: Impact of woody aliens on ecosystem properties. Pages 239–246 in I. A. W. Macdonald, F. J. Kruger, and A. A. Ferrar, The *ecology and management of biological invasions in Southern Africa.* Cape Town, South Africa: Oxford University Press. 2006

Wei, J. *et. al*.: A framework for selecting indicators to assess the sustainable development of the natural heritage site. Journal of Mountain Science 4: 2007.321-330

Young, A; Agroforestry *for soil management*; Wallingford, UK: CAB International, 1989.

Zimmerman, H. G.: Biological control of mesquite, *Prosopis* spp. (Fabaceae), in South Africa *Agriculture Ecosystems and Environment.* **37**: 175-186. 1991.

APPENDICES

Appendix I: Questionnaire for households in Salabani in Marigat

Background information

Name:

Gender:	1- male	2- female	
Marital status:	1- single	2- married	
Location:			
Level of education:	1-primary	2-secondary	3-college
	4- Adult education	5-none	
Occupation:	1.employed	2- pastoralist	3-farmer
	4-businessman	5- others	

1. In which year was *P. juliflora* introduced in this area?
2. What made the Government to introduce *P. juliflora* in this region?
3. What is the local name of *P. juliflora?*
4. Was the government justified in introducing *P. juliflora*?
5. What problems did you face before it was introduced?
6. What problems do you associate *P. juliflora* with, in Salabani? (List in order of severity)
8. Does *P. juliflora* have any negative effects on your health? If yes, List in order of importance/severity.
10. In your opinion, what are the benefits of this *P. juliflora*? (List In order of importance)
11 In your opinion should the Government eradicate this *P. juliflora*?
12. What is the land area of your farm and how much has been invaded by *P. juliflora*
13. How many people in your family have migrated because of *P. juliflora* invasion?
14. If any, what kind of assets did they leave behind e.g. land in hectares, houses and infrastructure? Estimate their values?
15 Before introduction of *P. juliflora* what was the land use in this area and on your own land holding?
16. Has the land use system changed since introduction of *P. juliflora*? If yes state how?
17. How has *P. juliflora* affected livestock on your farm?

Type	No affected	type of effects	value	Remarks
1. Cattle				
2. Sheep				
3. Donkey				
4. Poultry				
5. Goats				
6. Others				

18. What crops do you grow on your farm today as compared to1980 before introduction of *P. juliflora?*

19. What are the impacts of *P. juliflora* on the following social services?

    Education and access to schools

    Markets

    Cattle dips

    Grazing fields

    Cultural site

    Road network and communication

    Access to clean water

21. What traditional vegetables, fruits, trees, and shrubs have disappeared or emerged since *P. juliflora* invaded the area.

FLORA	EMERGED	DISAPPEARED
Vegetables		
Fruits		
Trees		
Shrubs		
Others		

22. What fauna have disappeared or emerged since the invasion of *P. juliflora*

FAUNA	EMERGED	DISAPPEARED
Insects		
Reptiles		
Mammals		
Birds		
Others		

23. What are the main uses of *P. juliflora* in this area? Estimate amount used monthly and monetary value where possible. Of the uses above give a priority ranking in terms of preference 5-very useful 4- useful 3- less useful 2- not common 1- not used

USES	**RANKING ORDER**	**AMOUNT PER MONTH**	**VALUE KSH**
Poles			
Firewood			
Fencing material			
Shade			
Charcoal			
Fodder			
Rehabilitation			
Medicinal			
Honey			
Food supplement			
Ornamental			
Timber			
Woodcarving			
Ropes			
Others			

Appendix II: checklist for research scientists at KEFRI, NEMA and Forest department

1. When was *P. juliflora* introduced in Salabani and by whom?

2. How did *P. juliflora* reach Salabani in Baringo District?

3. What is the origin of *P. juliflora*?

4. What is the global distribution of *P. juliflora?*

5. What are the utilization potentials of *P. juliflora*?

6. What are the wood properties of *P. juliflora*?

7. What efforts have been put in place to manage or eradicate *P. juliflora* in Marigat?

8. What management options exist for invasive *P. juliflora*?

9. Can *P. juliflora* be eradicated entirely? Explain.

10. What biological controls have been practiced elsewhere?

11. What government policies are in place for the management of *P. juliflora*?

12. How many charcoal permits does KFS issue for *P. juliflora* per month or annually in Marigat Forest station?

Appendix III: Checklist for Key Informants

1. Name of informant--------------- Institution-------------------------

2 What problems let to the introduction of *P. juliflora* in this region?

3. Has the introduction of *P. juliflora* solved the problems identified?

4 Who introduced *P. juliflora* in Salabani and when?

5 Has introduction of *P. juliflora* had any negative impacts on the environment, animals, land use or your health?

6 If the answer to Q5 is yes please name them in order of severity

7 Has wind erosion (Desert storms) been effectively controlled?

8 How has *P. juliflora* affected the following infrastructure?

(a)Roads

(b)Water pipes

9. What impact does the spread of *P. juliflora* have on the following Social Amenities?

(a) Education

(b) Markets

(c) Cattle dips

(d) Grazing field

(e) Watering points

(f) Cultural sites

10. What type of vegetation existed before introduction of *P. juliflora*?

11. What vegetation has disappeared or emerged since the introduction of *P. juliflora*?

12 What fauna has disappeared or emerged since the introduction of *P. juliflora*?

13 Are there any people who have moved away because of *P. juliflora* invasion?

14 If the answer to Q13 is yes please name them

15. Are there any cultural & historic sites affected by the invasion of *P. juliflora*?

16 If the answer to Q15 is yes please name them?

Appendix IV: Raw data of soil characteristics in the study area with different densities of *P. juliflora.*

P. density	PH	E.C	C	Organic matter	TN(ppm	TP(ppm)	K(ppm)	Na(ppm)	Ca(ppm)
None	7.87	0.131	0.12	0.206	0.04	2.9	287	83	2850
None	7.99	0.094	0.12	0.206	0.06	3.0	177	66	3053
Low	7.48	0.123	0.08	0.138	0.22	11.1	193	105	4553
Low	7.54	0.109	0.18	0.310	0.25	22.6	371	129	3957
Low	7.36	0.180	0.82	1.410	0.22	52.2	465	249	5332
High	7.35	0.196	0.99	1.703	0.91	33.1	383	274	4822
High	7.00	0.175	1.24	2.133	0.87	33.5	417	242	4768
High	7.08	0.124	2.27	3.464	0.88	50.3	233	259	3876

Source: Survey Data, 2009