Mapping and managing the spread of *Prosopis Juliflora* in Garissa County, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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DEDICATION

I dedicate this work to the memory of my late brother Hassan Zeila who went to meet his Maker while I was studying at Kenyatta University.

ACKNOWLEDGEMENT

I wish to acknowledge the enormous help I received from my two supervisors, Dr Anyango and Dr Waswa while carrying out my research work. I also acknowledge the cooperation of the many respondents and people I met in Garissa, who were forthcoming with the answers I have been seeking in my quest to know more about the invasive species *prosopis*.

This work would not have been complete without the understanding and support of my wife Hodhan.

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LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

ASALs	Arid and semiarid lands
FAO	Food and Agricultural Organisation
FD	Forestry Department
GIS	Geographic Information System
GPS	Global Positioning System
IUCN	World Conservation Union
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forestry Service
Landsat TM	Landsat Thematic Mapper
NEMA	National Environment Management Authority
NIB	National Irrigation Board
RCMRD	Regional Centre of Mapping of Resources for Development
Sp	Species

ABSTRACT

More than three decades after the introduction of prosopis species in the drylands of Kenya there is now increasing concern about the negative impacts of the plant on the livelihoods of dryland communities and on the ecological integrity of the fragile arid and semiarid lands. The extent of the species coverage in the arid and semiarid lands has, however, not been fully mapped owing in part to the recent nature of the problem. As such the aim of this study was to map out the extent of the spread of the species and propose community-friendly management options for this invasive plant. Geographic information system methodology and satellite imageries (Landsat images from 2000 and 2006), maps and GPS points were the main tools used for this work. Standard spatial statistical analysis procedures were employed using the software Erdas Imagine 8.4 and ESRI ArcView to generate land cover changes associated with prosopis species. The study found that a total of 440 square kilometres were newly colonised between the years 2000 and 2006, with Bura division having the highest area of land colonised at $143km^2$ (33% of total land area). The study also noted that the riverine land use/land cover system was the most infested, with $631km^2$ colonised. This automatically puts the livelihoods of thousands of pastoralists who depend on the River Tana ecosystem at risk. The study also employed a socio-economic survey that involved the use questionnaires and interviews to ascertain the perceptions of the local community regarding origin, impact and uses of the species. Eighty four per cent of the respondents indicated that prosopis' presence has had negative effect on the indigenous biodiversity of Garissa through loss of native vegetation. The three major local uses of prosopis were charcoal, fuelwood and animal fodder. The study shows that prosopis is a major environmental problem in the study area through its swift colonisation of strategic grazing reserves and is rapidly colonising new lands. The findings of this study call for commercialising production of prosopis for charcoal burning as a strategic management strategy for the plant. This should be accompanied with the use of efficient kilning technologies. In addition deliberate and pro-active policy changes should be put in place to delineate land specifically for this environmental business. Spread of the plant outside designated areas should be controlled by use of environment-friendly mechanical approaches. This further calls for community capacity building in partnership with key stakeholders like Kenya Forest Service. In this way, prosopis will cease to be a liability and instead contribute to community development through wealth creation.

CHAPTER ONE

INTRODUCTION

1.1 Background

Prosopis juliflora is a perennial deciduous thorny shrub or small tree commonly found in arid and semiarid lands (ASALs) but native to South America, Central America and the Caribbean, where it is known as mesquite or algarrobo. It can grow up to 10m tall, with a trunk diameter of up to 1.m. The common English names for *P. juliflora* are mesquite and honey mesquite. *Prosopis juliflora*, *P. pallida*, *P. chilensis*, *P. alba*, *P. pubenscenes* and *P. tamarugo* are all species that are native to the Americas, but have now become established in the arid and semiarid lands of Africa and Asia. *P. cineraria* is native to India. The honey mesquite can grow in areas that receive as little as 50mm annually. *Prosopis* was first introduced in Africa in 1822 in Senegal; subsequent introductions into Africa were in South Africa (1880) and Egypt (1900). In general, the mesquite species are well adapted to hot climates and a wide range of soil types and annual rainfall of between 150 and 1200mm. They are described as hardy because they can tolerate droughts and water logging, low nutrient soil and highly saline or alkaline soil (CRC, 2003).

The species was introduced into Kenya in the late 1970s by the National Irrigation Board (NIB), in association with the Kenya Forestry Research Institute (KEFRI) and the government of Finland, to help in solving environmental and energy problems in irrigation schemes in arid and semiarid lands (ASALs). *Prosopis* trees are drought-resistant and can help stem desert encroachment by growing where virtually nothing else will. They provide useful resources for poor communities because they require low investment to develop and manage. In addition, they can improve the livelihoods of desert margin communities by providing shade, high quality timber and firewood (Geesing *et al*., 2004). During the lifecycle of *Prosopis*, nutritious human food can be derived from its pods.

Prosopis trees are the source of valuable multipurpose products. In the Americas, there is a history of use of all parts of the tree: for example, tree products from *P. pallida* include wood (for timber, posts, poles, chips, charcoal and firewood) and pods (for fodder, flour, syrup, honey, resin gums, fibres, tannins and medicines). From Mexico to Peru, people have developed local economies based on *P. juliflora* and its products. Pods are stored year-round for fodder and may be made into flour or nutritious syrup. Honey is made and gums are collected. Products are either for family use or for sale in local markets. In Colombia and Venezuela, *Prosopis* is sometimes referred to as 'maiz criollo' ('local maize'), indicating its importance as a nutrient source for either man or animal (Pasiecznik, 2001).

1.2 Statement of the problem

Invasion and colonisation of lands by alien invasive species tend to have adverse impact on the lives, livelihoods and the native biodiversity of the colonised lands (Jama and Zeila, 2005). More than thirty years after the introduction of *Prosopis* into the drylands of Kenya, there is now increasing concern and debate about the negative impacts of the species on the lives, livelihoods and ecological integrity, as well as the possibilities for its control and perhaps total eradication. Thickets of *Prosopis* have become established in dry season grazing reserves (wetlands), croplands and along river courses. Concerns have been voiced on the impacts of the plant on the biodiversity of native species and on water resource dynamics in dryland streams. The species now features on the IUCN list of 100 world's worst invasive alien species

(Invasive Species Specialist Group of the IUCN, 2004). The species has been referred to as “the species of the politically disenfranchised”: those who do not have the means to undertake or demand development research into identifying uses and markets for this locally abundant species and who are vulnerable to environmental agencies which demand total eradication (Bakewell- Stone, 2006).

Communities living in the drylands have registered their complaints that centre on the adverse effects of the species’ powerful and poisonous thorns, its aggressive colonisation of useful habitats such as pasturelands and farmlands, its negative effect on animal health (which consume excessive amounts of seed pods), and its other unforeseen uses, including the use of the impenetrable thickets as hideouts by cattle rustlers in rustling-prone areas of northern Kenya.

The inhabitants of Garissa County are generally poor (ALRMP, 2006) and dependent on local natural resources for their well-being. Any changes in the biophysical environment will have far-reaching consequences on the livelihood support systems of these resource-dependent communities. Little attempts have been made to map and inventorize and the spread of the species using large-scale observation methodologies and the attendant implications. Anderson (2005) carried out a systematic study on the “Spread of the introduced tree species *Prosopis juliflora* in the Lake Baringo area, Kenya,” in which he attempted to map the spread of the species from the initial planting sites. However, no attempt has been made to calculate the extent of colonisation of grazing and pasturelands in Garissa County, which has been cited as one of the Countiess that have been particularly hard-hit by the species (Choge et al., 2004). Little efforts have been made to explore the possibilities for promoting alternative uses of the species for such beneficial economic uses as charcoal and timber production.

This study therefore sought to fill the existing academic lacuna on the extent of the problem in Garissa County from a Geographic Information System (GIS) and socio-economic standpoint. The research investigated the perceptions and attitudes of the affected pastoralist community in the County regarding the invasion and colonisation of their land by the species. The study also provided information on the extent of environmental and socio-economic impacts of the species in the arid and semiarid lands of Kenya, besides suggesting possible remedial actions, at both the technical and policy levels.

1.3 Research Questions

This study was guided by the following research questions:

i. What is the percentage of the total land area in Garissa County that has been invaded and colonised by *Prosopis juliflora* species between the years 2000 and 2006?
ii. What are the perceptions of the pastoralist community in Garissa County on *Prosopis* invasion and colonisation?
iii. What are the implications of prosopis invasion in terms of environmental quality and community well-being?
iv. What are the options for sustainable management of this plant?

1.4 Objectives of the research

The objectives of this research were:

i. To map the total area that has been invaded and colonised by *prosopis* species between the years 2000 and 2006 in Garissa;
ii. To analyse the perceptions of the pastoralist community in Garissa County on *prosopis* invasion and colonisation in the County;
iii. To assess the socio-economic effects of the plant on community livelihoods;
iv. To design an environment- and people-friendly management framework for *prosopis*

1.6 Justification and Anticipated Output

The findings of this study will provide government agencies dealing with dryland development with the scientific and socio-economic information necessary for promulgating programmes that aim at arresting the spread of the species while at the same time contributing to wealth creation in the County. The experiences and attitudes among the rural communities towards prosopis collected through surveys and interviews can be used as ingredients in the design of an appropriate prosopis management plan.

The outputs in this study will include geo-referenced maps of *prosopis* colonisation and coverage in 2000 and 2006 as well as socio-economic information on community percentages regarding presence of *prosopis* in their area.

1.7 Conceptual Framework

The study was conceptualised from the perspective that arid ecosystems support diverse livelihoods, especially pastoralism. Arid lands are also characterised by varied biodiversity. The nomadic pastoralists living in the area have witnessed their land slowly losing its productivity and value due to a combination of factors, including changing climatic patterns that have resulted in year-on-year reduced annual precipitation in the greater Sahel, of which northern Kenya is part of, for the last four decades (Sene, 1998). This has been made worse by the onset of *prosopis* colonisation, which started in the late 1980s and sprinted out of control by the mid 1990s (Choge *et al*., 2002)

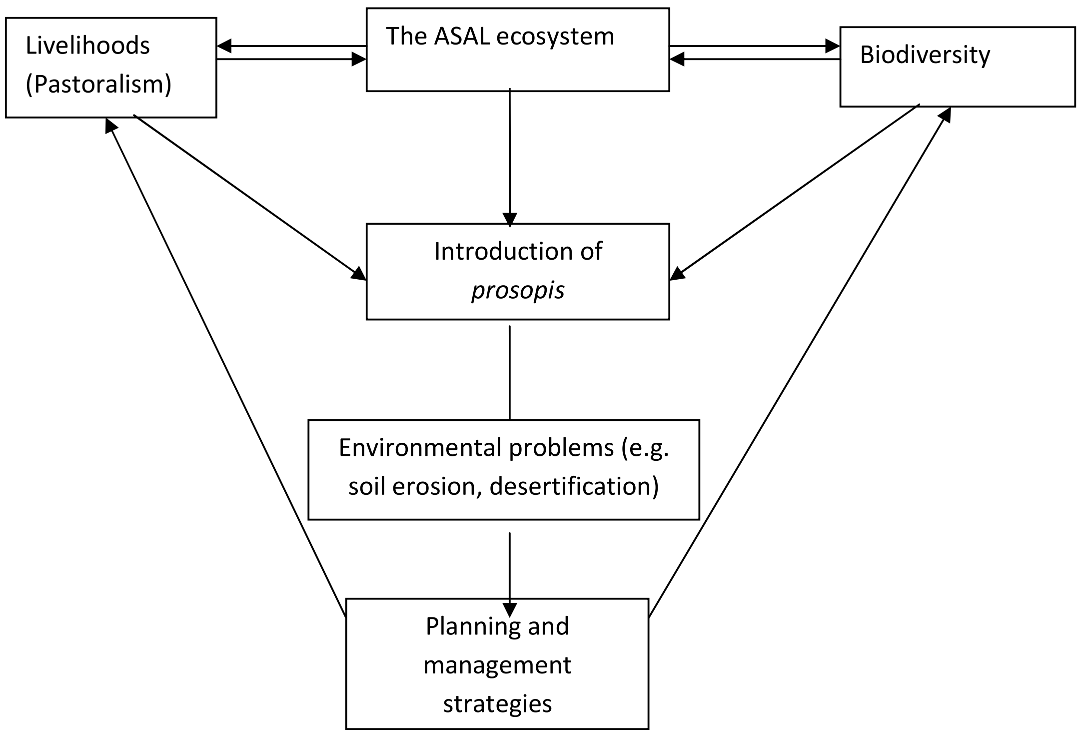


Figure 1.1: Conceptual framework (*Source: author*)

Prosopis was introduced in the arid lands with the intention of arresting soil erosion, ensuring self-sufficiency in wood products, making the environment habitable and safeguarding the existing natural vegetation from over-exploitation by the rising human populations. *Prosopis* proved that to be a hardy plant which is fast-growing, drought- and salt-resistant, and with remarkable coppicing power.

The study recognises that any introduction of a species to an environment where it is not native may result in its rapid spread, often to the detriment of indigenous biodiversity. This is likely to negatively affect livelihood and biodiversity of arid lands. The study has delineated the extent of coverage of prosopis species in Garissa by administrative boundaries and by land use/land cover classification. This study will add value to the national programmes aimed at controlling the spread of prosopis by mapping out the affected areas and the costs associated with the presence of the species on land, enabling policy makers and other stakeholders draw up effective management plans.

1.8 Limitation of the Study

i. The study recognizes that there is advancement in the techniques for mapping the spread of invasive alien species than the technique used in this study. The results obtained hold for the purpose of this study and can be generalised.
ii. The study is limited in terms of spectral resolution by using Landsat TM imageries for acquisition of scenes mainly due to the very cost implications in acquiring imageries with much higher spectral resolutions such as QuickBird.

1.9 Definition of Key Terms

Imageries: Pictorial images from remote sensing platforms.

Landsat: Satellites that provide repetitive coverage of continental Earth surfaces in the visible, near-infrared, short wave and thermal infrared regions of the electromagnetic spectrum.

Invasive species: Also called “invasive exotics,” is a nomenclature term and categorisation phrase used for non-indigenous flora that adversely affects ecosystems to which they are introduced.

Mapping: Refers to the making of maps, as in cartography, surveying and photogrammetry.

Rasterized images: Collection of dots called pixels, whose resolution is expressed in dots per inch (dpi).

Vector image: Is a collection of connected lines and curves that produce objects, whose resolution is defined by maths and not pixels.

Pixels: Picture elements, used in digital imaging to refer to a single point in a raster image (smallest addressable screen element).

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Invasive Species in General

Exotic plant species have been introduced worldwide due to their economic, environmental or aesthetic values. Some accidental introductions have also occurred through time. Nevertheless, introduction of new species is not always a success and one of the problems linked to this is the possibility of these species becoming invasive. The invasive 'aliens' often have negative economic, environmental and/or social impacts. These include reduction of grazing areas, reduction of crop yield, risk of threat to biodiversity, disruption of water flow, livestock poisoning and the formation of impenetrable thickets (Andersson, 2005).

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

It is important to note that not every exotic plant species become invasive weeds. Only a few of the introduced plant species form viable stands/populations and even fewer naturalize to the new environment. It has been estimated that only one or two percent of introduced exotic plants become invasive weeds (Groves, 1986). However, it is difficult to predict whether a plant species has the ability to spread uncontrollably. A common phenomenon with introduced plant species is a so called 'time lag', where the plants only start to show invasive tendencies after a period of so many years to many decades (Hughes, 1994; Mooney and Cleland, 2001). There are three main strategies to control or eradicate invasive species: physical (where plants are mechanically removed), chemical (where herbicides are used against plants), and biological (where predators or pathogens are used to control the invading plant's reproduction) (Hobbs & Humphries, 1995; Geesing *et al.,* 2004).

The 'prosopis debate' has become an important topic of discussion and policy in Kenya during recent years, due primarily to *Prosopis juliflora* becoming an aggressive weed in several districts. Invasion of grasslands, riverine forests and nature reserves has alarmed ecologists. Invasion of irrigation channels and arable land has affected the agricultural community, while pastoralists have seen the dwindling of their pasturelands. These groups have put pressure on the government through petitions and court actions, and the government has been forced to stop further planting of *P. juliflora* and begin eradication programmes, most notably in Baringo County.

However, there are also many people who hold the view that prosopis is a valuable resource in the drylands and that in any case eradication is a virtual impossibility, arguing that there is need to control the species through exploitation.

2.2 The Ecology of *Prosopis Spp*

Prosopis juliflora (Sw.) DC. is an evergreen tree native to northern South America, Central America and the Caribbean (Pasiecznik, *et al*., 2004). It is fast growing, nitrogen-fixing and tolerant of arid conditions and saline soils (Anonymous, 2003;

Pasiecznik *et al.,* 2004). *P. juliflora* has a large crown and an open canopy and can grow to a height of 14 meters (Anonymous, 2003). Its stem is green-brown, sinuous and twisted with axial and strong thorns. Its bark is red-brownish and rough and the root system has a deep taproot system that allows the tree to reach deep water tables. The leaves are compound (Figure 2), dark bluish-green and have high tannin content (Pasie-cznik et al 2001, Matthews & Brand 2004). The foliage is unpalatable for livestock, except for very tender new shoots (Anonymous 2003). P. juliflora flowers throughout the year with yellow flowers hanging from the branches. Its fruits are pods, which are green when immature and turn yellow when they mature (Masilamani and Vadivelu, 1997). The pods contain a high level of sugar (Talpada & Shukla 1988, Batista et al 2002) and are palatable to livestock when ripe (Anonymous 2003). A mature P. juliflora tree can produce 40 kg of pods per year, from which 60 000 seeds can be obtained (Alban et al 2002).

Fast-growing, drought- and salt-resistant, and with remarkable coppicing power, Prosopis has succeeded in colonising large swathes of drylands in Kenya. The species mainly reproduces via seeds, producing one main crop annually. Each seed pod generally carries between 5 and 20 seeds, with potentially hundreds of thousands of seeds produced per mature plant. Animals consume the nutritious seed pods and excrete viable seeds in their droppings, helping to spread mesquite over shorter distances. Cattle are mainly responsible, although horses, pigs, goats and sheep are also known to consume the seed pods. As long as the seeds themselves are not damaged by chewing the process of digestion actually helps germination, especially since the expelled seeds are deposited in moist, nutrient-rich dung. Seed pods are also spread by flooding (CRC, 2003).

Previous studies showed that *P. juliflora* is performing better under drought stresses compared to native species. High seed germination rates gives *P. juliflora* great opportunities to grow faster and better and makes of it a more adapted species to drought conditions compared to other native species (Al – Rawahy *et al*, 2003). In their study in Oman, Al –Rawahy *et al*., (2003) concluded that the number of *prosopis* seeds in seed banks is greater than the seeds of native tree species. *Prosopis* accumulate long-lived dormant but viable seeds in the soil serving as sources of regeneration of new *prosopis* plants in the event of disturbance that might eliminate the aboveground stands (Shiferaw *et al*., 2004).

Even under optimal conditions only a portion of the seeds will germinate at any one time: in experiments done in Ethiopia, only few seeds (21%) germinated, suggesting that the seeds have high dormancy caused by the hard seed coat. This is particularly important for species survival in arid environments characterized by their spatial and temporal unpredictability in rainfalls. This is an opportunistic behaviour of *P. juliflora* comprising two main ecological factors: seed ecology of *prosopis* and allelophatic effects of *prosopis* relative to other species (Shiferaw et al., 2004). Shiferaw reported that *prosopis* plants possess allelochemicals that inhibit the germination and spread of other plant species. This mechanism, combined with drought conditions, can inhabit other species and eliminate any kind of competition.

The species has been declared a noxious weed in many countries, including Kenya by NEMA.

2.3 Ecology of *Prosopis juliflora*

Invading *Prosopis juliflora* tends to form dense, impenetrable thickets, associated with unfavourable impacts on human economic activities. Millions of hectares of rangelands have already been invaded, and the process is still occurring in South Africa, Australia and coastal Asia (Zeila et al., 2004). It is one of the three top priority invasive species in Ethiopia and has been declared a noxious weed. Sudan has passed a law to eradicate it (Jama and Zeila, 2005).

Land use changes, competitive ecological advantages, and climate change are key factors thought to influence the probability of invasion (Pasiecznik et al., 2001). In northern India, *Prosopis 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 *Prosopis* plants (Aboud *et al*., 2005).

Seed production is estimated at 630,000 to 980,000 seeds per mature tree per year. Those seeds are most likely to germinate when the sugary pods are consumed by domestic livestock, the seeds scoured while passing through the animals' digestive tract, and the scoured seeds dropped into moist faeces (Felker, 1996). In South Africa, it is estimated that *Prosopis spp*. reduce mean annual run off by about 481 million cubic meters across the country (Choge *et al*., 2002).

For over fifty years, ranchers in south-western USA and Argentina tried a range of techniques to eradicate or control *Prosopis* (Pasiecznik et al., 2001). Despite the high costs of eradication, a cost effective program is yet to be found. 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 land use to its management and use (Felker, 1996). Reduction in stocking rates can encourage good grass cover, which may prevent seedling establishment.

2.4 Introduction of *Prosopis* into Kenya

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, among others. In Africa, *Prosopis* was introduced in 25 countries spanning all regions of the continent. While records indicate that the earliest introductions to Africa may have been in Senegal, South Africa, and Egypt in the early to late 19th century, earlier introductions may have occurred (Pasiecznick et al., 2001).

The first documented introductions of *Prosopis juliflora* and *Prosopis pallida* to Kenya was in 1973 for the rehabilitation of quarries near the coastal city of Mombasa, with seed sourced from Brazil and Hawaii (Jama and Zeila, 2005). In the early 1980s *P. juliflora* was introduced in the Lake Baringo area through the Fuelwood Afforestation Extension Project (Kariuki, 1993; Lenachuru, 2003). The major objectives of the project was to involve the local people in tree planting to overcome problems such as lack of firewood and overgrazing (Kariuki, 1993; Lenachuru, 2003).

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 Garissa area of north-eastern Kenya and in the Lake Turkana and Pokot areas in northwestern region of the country.

Prosopis was first introduced in Bura in 1983 when a forester working for the State's National Irrigation Board (NIB) established a pilot 10 ha plantation near Bura town, using seed of unknown provenance sourced from a commercial tree seed supplier in the Netherlands (Zeila et al., 2004). It is after this introduction at Bura that the species' prolific growth abilities saw to it that it expanded its coverage in all directions, including spreading to the neighbouring Garissa County.

2.5 Socio-economic and Environmental Importance of *Prosopis juliflora*

Prosopis tends to have severe impact in riverine areas and in the savannah pasturelands because of the availability of localised soil moisture (Geesing *et al.*, 2004). The riverine forests are one of the most bio-diverse natural ecosystems to be found in the drylands of Kenya, hosting an enormously wide range of distinct flora and fauna. They are highly valued locally and are of significant socio-economic benefit to rural communities. The pasturelands host much of Kenya's livestock population, and these herds stand to lose when dense impenetrable thickets of prosopis restrict their movement in search of water.

Riverine forests are increasingly being invaded by prosopis, thus threatening indigenous species. According to SOS Sahel & MoA (1999) prosopis actually does not invade closed riverine forests as it is not shade tolerant but spreads into clear or partially clear areas. In some parts of northern Kenya, pastoralists clear paths within the riverine forest system to create access paths for their livestock to move when seeking water. Native species that can be found in the riverine forests and that are under increasing threat from fast spreading prosopis include *Hyphaene corriacea* (doum palm), *Acacia tortilis*, *Acacia nilotica, Acacia seyal, Acacia mellifera,* *Zizyphus mauritiana* and *Boscia* spp. In addition to this, prosopis infestation also poses a risk to the riverine wildlife that stand to lose their habitat.

Prosopis has the technical timber and pod qualities, and environmental attributes, to be a species of worldwide commercial importance. Demonstrable successes with Prosopis products include firewood, charcoal, building materials, floor tiles, furniture, and handicrafts. Other potential opportunities involving non-wood products include processing for livestock feed, human food, possible medicinal value, gum production, and tannin extraction (Aboud *et al*., 2005).

Prosopis trees are the source of multi-purpose, valuable products. In the Americas, there is a history of using all tree parts, for example, tree products from *P. pallida* include wood (for timber, posts, poles, chips, charcoal, firewood) and pods (for fodder, flour, syrup, honey, resin gums, fibres, tannins and medicines). From Mexico to Peru, people have developed local economies based *P. juliflora* and its products. Pods are stored year-round for fodder and may be made into flour or nutritious syrup. Honey is made and gums are collected. Products are either for family use or for sale in local markets. In Colombia and Venezuela, prosopis is sometimes referred to as ‘maíz criollo’ (‘local maize’), indicating its importance as a nutrient source for either man or animal (Pasiecznik, 2001).

The wood is probably the single most important natural resource from Prosopis species for either fuel or for construction purposes. As a timber it can be used for poles or round wood, or cut into boards and cants. P. juliflora can grow up to 10 metres tall, with a trunk up to 1.2 metres in diameter (Jama and Zeila, 2005). Prosopis has potential uses in the wood carving industry, parquet/flooring tiles, high-value furniture, fibreboards and railway crossbeams. It is rarely used in large-scale construction, however, because most trunks are not straight or long enough (Pasiecznik, 2001).

Fruit pods are high in sugar and protein and are a rich food source for humans and animals. Felker (1996) reports that ‘extensive anthropological data on human food uses of Prosopis pods and food technological experiments have demonstrated conclusively the potential of mesquite pods in human food preparation’.

Prosopis flowers are an important source of pollen and nectar, and native pollinators are attracted to their bright colours, making them important in apiculture. Honey produced from Prosopis flowers is of high quality, as is gum. The exudate gums from the trunk and branches can be used in various industrial sectors such as food, pharmaceutical, chemical and manufacturing. The gum forms adhesive mucilage and can be used as an emulsifying agent in confectionary and for mending pottery.

Other Prosopis products include tannins, dyes, and living fencing. The bark is rich in tannin and can be used for roofing. Prosopis is a folk remedy in some arid zones of the world for catarrh, colds, diarrhoea, dysentery, excrescences, eye problems, flu, colds, hoarseness, inflammation, itch, measles, pinkeye, stomach ache, sore throat and wounds (Felker, 1996). Finally, useful services provided by the tree include shade, soil stabilisation and carbon sequestration (Jama and Zeila, 2005).

2.6 Dilemma of utilizing or eradicating Prosopis:

South Africa offers a case study in attempting eradiation of prosopis (Campbell, 2000). Attempts at eradication, using chemical and mechanical programmes, began in the fifties but have failed. Treatment of cut stumps with picloram (Tordon^{TM}) in diesel was the standard method used for many years. However, the high costs of control and the environmental risks associated with this herbicide made large scale control operations impossible. Control costs often far exceeded the value of the land.

Successful control was therefore not possible without large scale intervention by the State. Foliar applications by air turned out to be unsuccessful and even more costly. The situation was further aggravated by conflicts of interest between those who used prosopis trees as a resource, and opponents who saw them only as pests. Landowners at the periphery of invasions, or those who have only scattered trees, benefited from prosopis, but once populations had reached a certain density, they reverted to multi-stemmed, dense, impenetrable thickets that also ceased to produce pods because of intra-specific competition, and so the once valuable tree lost all its positive attributes. Today more than 2 million hectares in South Africa have been invaded to some degree and prosopis is continuing to expand its range.

2.7 Summary of Research Gaps

Owing to the fact that it is a relatively new phenomenon there is not much academic research that has gone to map out areas affected by prosopis in northern Kenya. One challenge that has faced researchers has been differentiating the spectral signature of prosopis from the spectral signatures of the other green foliage in the area when using low spectral resolution GIS platforms such as Landsat. Additionally, there are gaps in documenting the economic implications of prosopis invasion of pasturelands amongst pure pastoralists such as the Somali of northern Kenya.

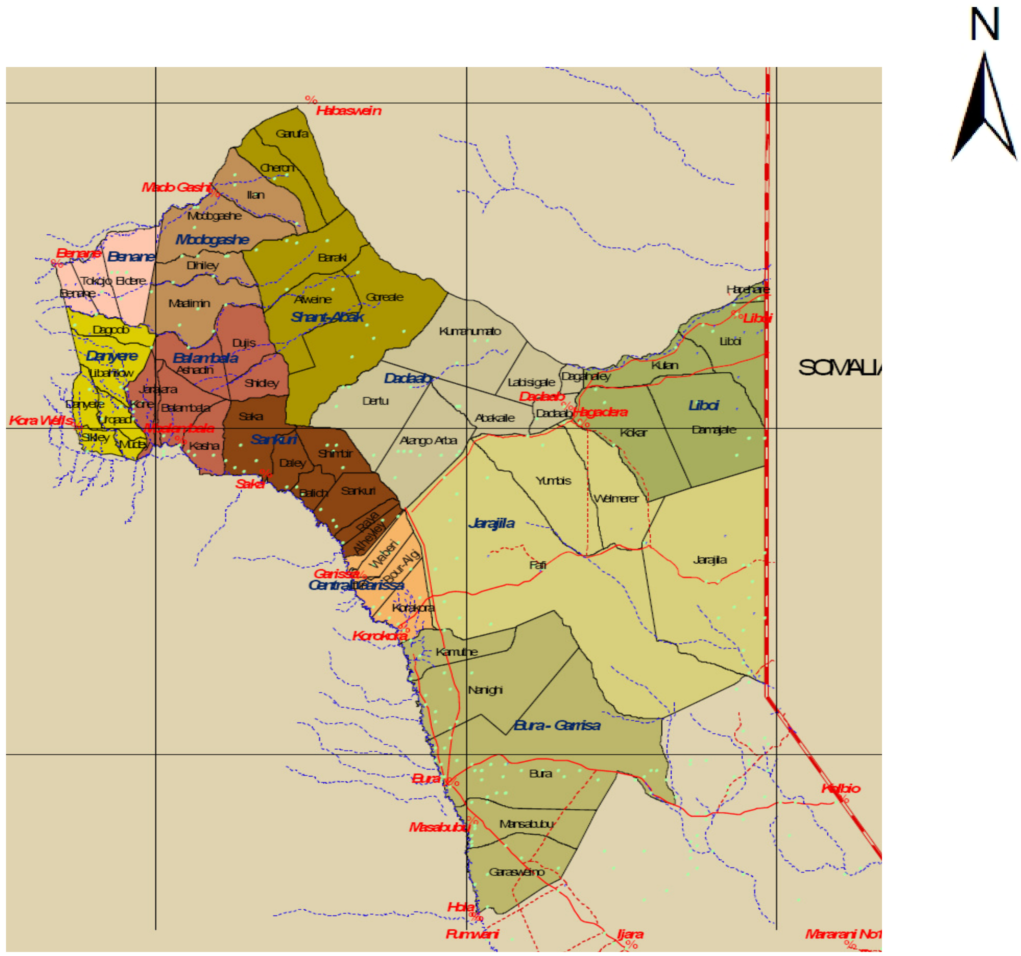
CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area Description

The study focused on Garissa County, which is one of the four former districts forming the vast North Eastern Province, and it covers an area of 43,259 km^2. The County lies between latitude 00 58 and 0^0 2'S and longitude 38^0 34'E. The County borders Wajir County to the North, Ijara district to the South, Tana River and Isiolo district to the West and Republic of Somalia to the East. The County covers an area of about 7.45% of the total area of the country. The length of the County is approximately 333km and its width is 248km. It has eleven administrative divisions (ALRMP II, 2006).

The mean rainfall ranges from 236mm and 342mm. Garissa is low lying with altitude varying between 70m to 400m above sea level. The County has about 300,000 people. The soils range from sandstones (Balambala Division), dark clays in some patches (southern divisions) to fertile alluvial soils along the River Tana Basin. Except for the sandstones and the clays, the rest are fertile soils suitable for crop production in regions with adequate rainfall. The County's vegetation is mainly scrubland interspersed with Acacia trees (ALRMP II, 2006). Nomadism is the most common land use activity in the region (Figure 3.1).



Scale*: 1:100,000* Source*: ALRMP (2003)*

Figure 3.1 Location of study area

3.2 Study Design

3.2.1 Spatial Data Methods and Procedure

The study used remote sensing and GIS techniques to investigate the extent of the spread of the species in the study area, where satellite imageries, GPS points and maps were used as data sources. Landsat^{TM} images from years 2000 and 2006 were used to generate land cover associated with *Prosopis* sp. The selected imageries for the study had minimal cloud cover (10% or less). Eight adjacent scenes of anniversary LANDSAT-TM images of the region on two different dates with path-row IDs shown in Fig 3.2 were acquired to cover the study area. These were LANDSAT-TM (September 19, 2000); LANDSAT-TM (September 23, 2006).

Sites in the study area were then visited for ground-truthing where GPS points/polygons collected from the field were used to generate training sites (sample points). The training sites were selected based on the existence of *Prosopis* vegetation in the field and class signatures derived from the image. Pre-knowledge of the phenology of *Prosopis juliflora* informs us that this plant is ever-green throughout the year, with minimal change in its floristic character occurring during its flowering period which roughly coincides with the rainy season. September, the driest month in Garissa, was therefore considered ideal for the study as it offered an opportunity to distinguish *Prosopis juliflora* from other non-deciduous flora.

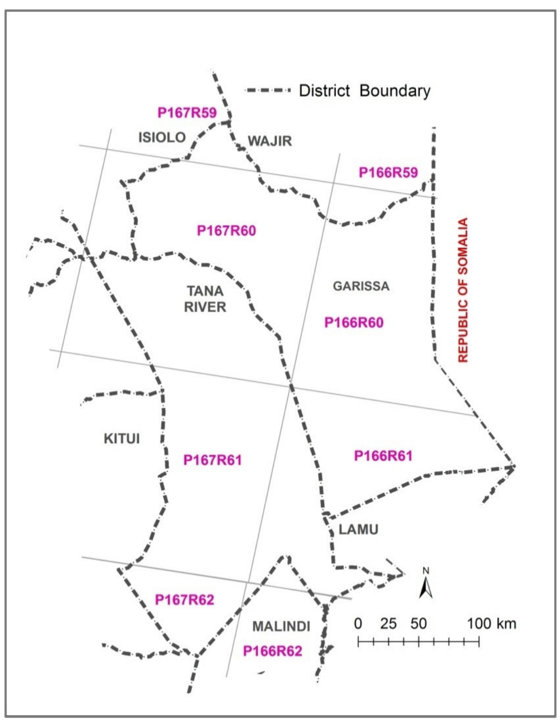


Figure. 3.2: Landsat TM Reference grid showing path-row IDs of selected scenes

The software used in this study included ERDAS Imagine 8.4 for geo-rectification and image processing, ESRI ArcView 3.2 software for digitization, production of vector GIS layers and for performing GIS analysis, and MS Excel for statistical analysis. The hardware used included a desktop PC Pentium IV 3.2 GHz speed.

Prosopis juliflora coverage estimates were derived from imagery using the Sub-pixel Classifier, an add-on module to ERDAS Imagine software. The sub-pixel classifier within ERDAS Imagine performed a supervised, non-parametric spectral detection and quantification for a specific material of interest (MOI) at a sub-pixel, or 30m x 30m, level. This allowed the determination of the percentage of the MOI within a pixel, from 20% to 100%, using a spectral signature. This process allowed the study to discriminate between multiple MOIs within a mixed pixel (a pixel that contains more than one signature).

The flow chart in Figure 3.3 below depicts a six-step procedure used to accomplish the sub-pixel classification, that is, quality assurance and artefact removal making the subjected satellite data free from different noise errors, pre-processing for identifying various potential spectral backgrounds, environmental correction to calculate atmospheric and solar correction factors, signature derivation and MOI classification by using sub-pixel classification technique.

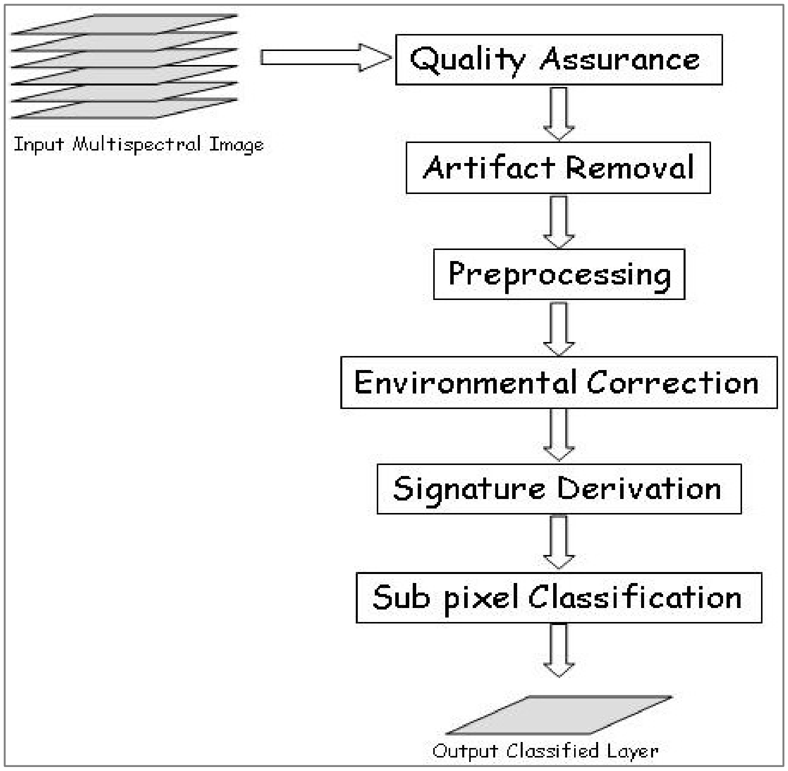


Figure. 3.3: Generic sub-pixel classification workflow
(*Source: author*)

To begin with, all scenes were radiometrically calibrated, converted to top-of-atmosphere reflectance images, corrected for topographic illumination effects, and temporally normalized between scenes, and cloud and shadow masked. Bands 4, 3, and 2 were then subset from each year's image and layer stacked into two false colour composite images for year 2000 and 2006. Each of the scenes for the two dates was rectified to UTM WGS 1984 Zone 37N and 37S as appropriate. The datum was selected to match the geographic projections of ancillary datasets. The images were then mosaiced and clipped using shapefiles of the study area.

To develop a signature for an MOI for the year 2000, the following steps were taken. First, an area of interest was developed using pixels that are known to contain the target MOI ("training pixels"). The Global Positioning System (GPS) was used to locate specific areas to determine the approximate percent coverage for each target MOI (Aspinall and Veitor, 1993). The corresponding pixels for these areas were located and used to develop training pixels. Automatic signature derivation, which takes all training pixels for a specific MOI and evaluates them for a common composition of spectral measurements (that is, absorption and reflectance values) was used to produce the initial MOI signatures. Fifty new locations were selected, downloaded to GPS, and field validated to account for variability within the signature. This yielded a signature useful for the final analyses of the Landsat imagery for the *Prosopis juliflora* spp MOI.

Multiple classifications were run for the MOI on the selected image by varying spectral criteria, i.e. acceptable standard error. All classification runs were compared to ground data and evaluated using linear regression. The strongest (most accurate) run for the MOI was then selected and used for all further data analyses.

The remaining year 2006 was classified independently following the same procedure outlined above.

The classification output raster layers for the two dates were sequentially exported to ESRI's 9.3 Arcmap environment with the ArcGIS Spatial Analyst Extension activated. Using the reclassify tool, it was possible to mask the areas into 'present' and 'absent' for *Prosopis juliflora* infestation. The 'absent' areas were recorded as 'no data' and the output converted to ESRI shapefiles. Combining rasterized recoded shapefiles of the administrative divisions with the *prosopis* coverage for each date enabled estimation of the frequency of *prosopis* coverage per division. This was multiplied by the cell-size of the raster output to get the estimated areal coverage. The procedure was repeated for the landuse/land cover shapefile.

Two maps (years 2000 and 2006) on the extent of *Prosopis* cover of the area were generated to compare and quantify temporal changes in *Prosopis* land cover. The 2006 *Prosopis* invasion extent was then calculated and the species coverage thereafter calculated using overlays of vector files of divisions of the study area to estimate the area covered by *Prosopis*.

3.2.2 Socio-economic survey

The study also employed a socio-economic survey that involved the use of both qualitative and quantitative techniques to establish the perceptions of the local community regarding origin, impact and beneficial uses of the species. This survey was conducted in three divisions of Garissa County that were selected on based on discussions with community opinion leaders on the extent of colonisation by *prosopis*, namely Bura, Sankuri and Bangale. Both quantitative and qualitative approaches were used for data collection in the survey. These included researcher-administered household questionnaires (Appendix 1) with both open-ended and closed questions. Key informant interview guide was used to interview key stakeholders such as local government officials and local NGO and CBO personnel, including community members: interviews were done with eight knowledgeable persons equally across the gender divide. Six focal group discussions were also held, with each group consisting of approximately eleven members.

3.2.2.1 Target Population and Sampling Procedure

Community members and opinion leaders living in Garissa constituted the target population for this study. The unit of observation was the head of households. A multistage sampling procedure was used. Firstly, purposive sampling was used to identify the divisions based on extent of *prosopis* colonisation. Thereafter, in each division, a random sampling technique was used to select the locations for sampling. In each location, random sampling was also used to identify the households to be interviewed.

The sample size was calculated using the Fisher's Equation:

$$n = \frac{t^2 \times p(1-p)}{m^2}$$

where n = required sample size

t = confidence level at 95% (standard value of 1.96)

p = proportion of target population with the desired characteristics

m = margin of error at 5% (standard value of 0.05)

Calculation:

$$n = \frac{1.96^2 \times .60\,(1-.60)}{.05^2} = 316$$

The sample was further increased by 5% to account for contingencies such as non-response or recording errors, resulting into 332 households. Thereafter, considering the cluster group proportionately in the selected divisions, the household interviews were distributed as follows:

Table 3.1: Distribution of household questionnaires per division

Division	No of households	Received
Bura	140	140
Sankuri	110	110
Bangale	82	82
Total	332	332

3.3 Data processing, analysis and presentation

Quantitative data was entered using MS Access database software and later converted into the Statistical Package for Social Science (SPSS) which was used for analysis. Qualitative data was triangulated and analysed based on thematic areas and were mainly used in this thesis for detailed explanation of the quantitative aspects of the study. Descriptive statistics, frequency, standard deviations, and chi-square tests were used where appropriate depending on specific research objectives to test for differences between variables and treatments. The results are presented in the form of frequencies and percentages.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This section of the thesis report provides results from the qualitative and quantitative data that was collected in the field. For clarity and flow, results from questionnaires and the Landsat mapping of *prosopis* distribution have been integrated into the discussions.

The study used remote sensing technology and GIS software and adapted a methodology for mapping the spread of the species in the years 2000 and 2006, enabling reasonably accurate assessment of the spread of the species in that period. The study also captured vital information regarding peoples' perceptions on the origin, spread, effect and management options regarding the invasive species Prosopis juliflora. This is crucial for the collection of data, local experiences and attitudes towards prosopis and enables one to draw a broader picture on the ecological and socio-economic impact the species has in northern Kenya, particularly in the view of the lack of available information and research on the subject there.

4.2 Socio-demographic characteristics

In total, 332 household respondents were interviewed in the 3 divisions. Out of these 60% were male-headed while 40% were female-headed. This indicates that while this is a patriarchal society, with the majority of households being headed by men, a significant number of households are headed by women. The main occupation was mainly livestock rearing (40%) and farming (30%) along the River Tana system. The people rely heavily on livestock as their main source of livelihood and engage in casual wage employment as supplemental income. This can be attributed to the recurrent droughts in the area that has seen majority of the households lose their herds.

Table 4.1: Socio-economic characteristics of the respondents

Characteristic	Description	Frequency	Percent
Sex	Male	199	60
n=332	Female	133	40
Occupation	Livestock rearing	132	40
	Farming	99	30
n=332	Wage employment	66	20
	Trading	30	9
	Others	5	1

4.3 Estimation of area invaded and colonised by *Prosopis* species

Figures 4.1 and 4.2 below shows the clips of Landsat satellite imageries superimposed on the County boundaries. This indicates a false colour imagery presentation where the red portion representing infrared part of the spectrum depicts green vegetation cover. The various expression of vegetation in several categories are based on their specific red tints and in most cases from the spatial patterns they occupy. The false colour composite consider a different combination of colours and bands (Band 4 = blue, Band 3 = red and Band 2 = green).

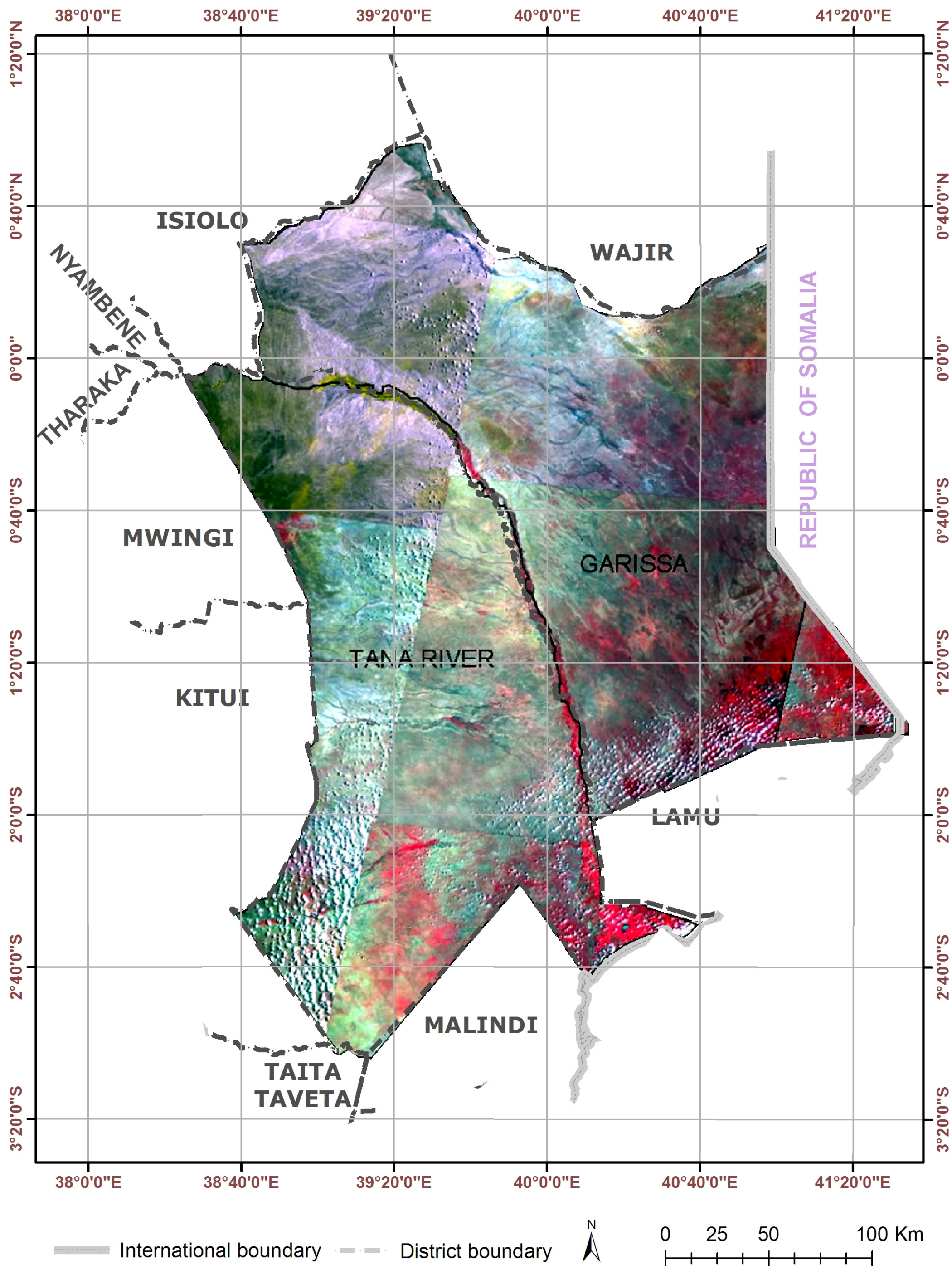


Figure 4.1: Year 2000 Landsat band 4-3-2 False Colour

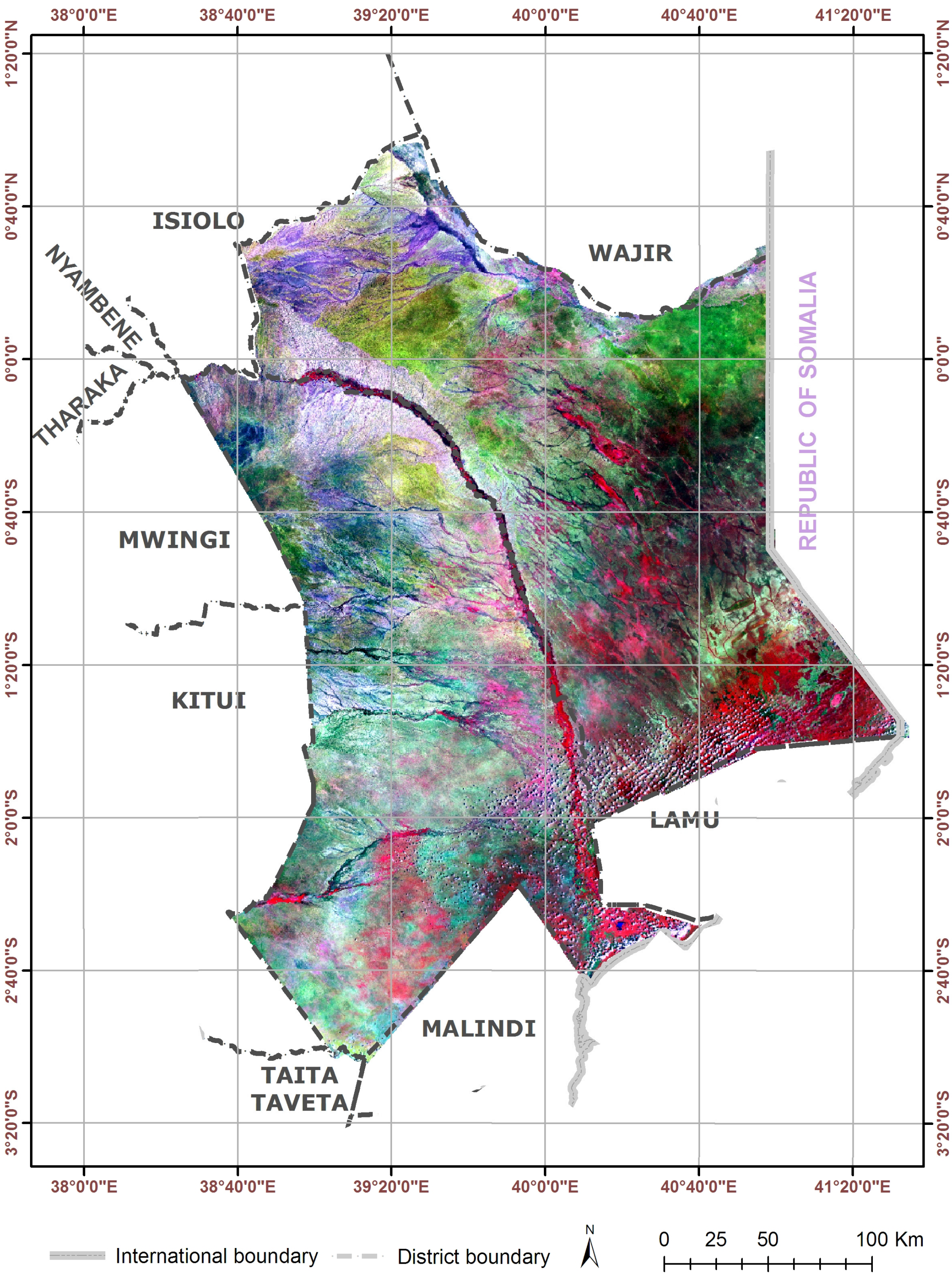


Figure 4.2: Year 2006 Landsat band 4-3-2 False Colour

Prosopis juliflora coverage estimates were derived from imagery using the sub-pixel Classifier. The sub-pixel classifier within ERDAS Imagine performed a supervised, non-parametric spectral detection as explained in the methodology. The figures 4.3 and 4.4 below show the extent of *prosopis* infestation and coverage in the years 2000 and 2006, superimposed on administrative boundaries (divisional and County) and the Tana River system.

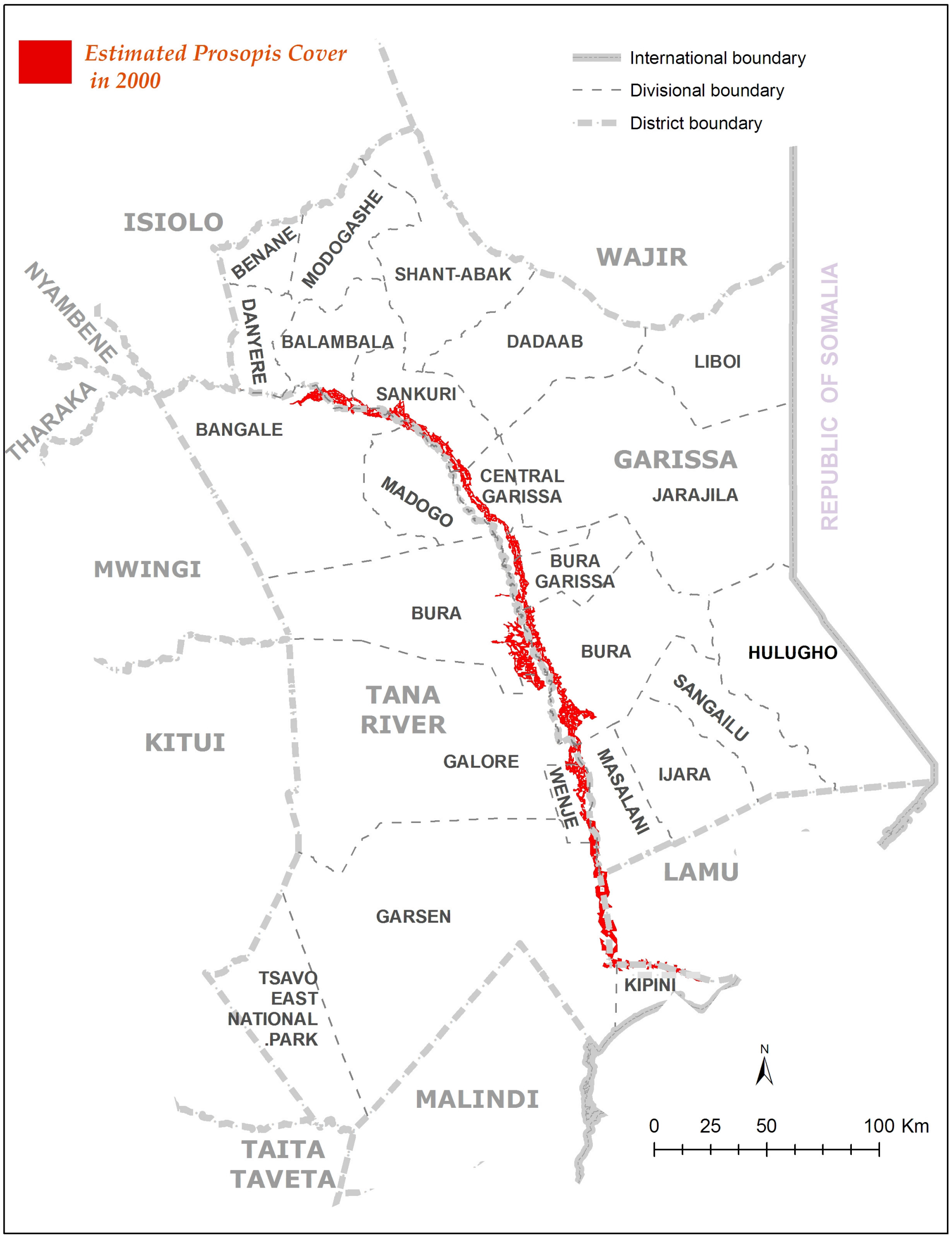


Figure 4.3: Estimated prosopis cover in year 2000 in Garissa

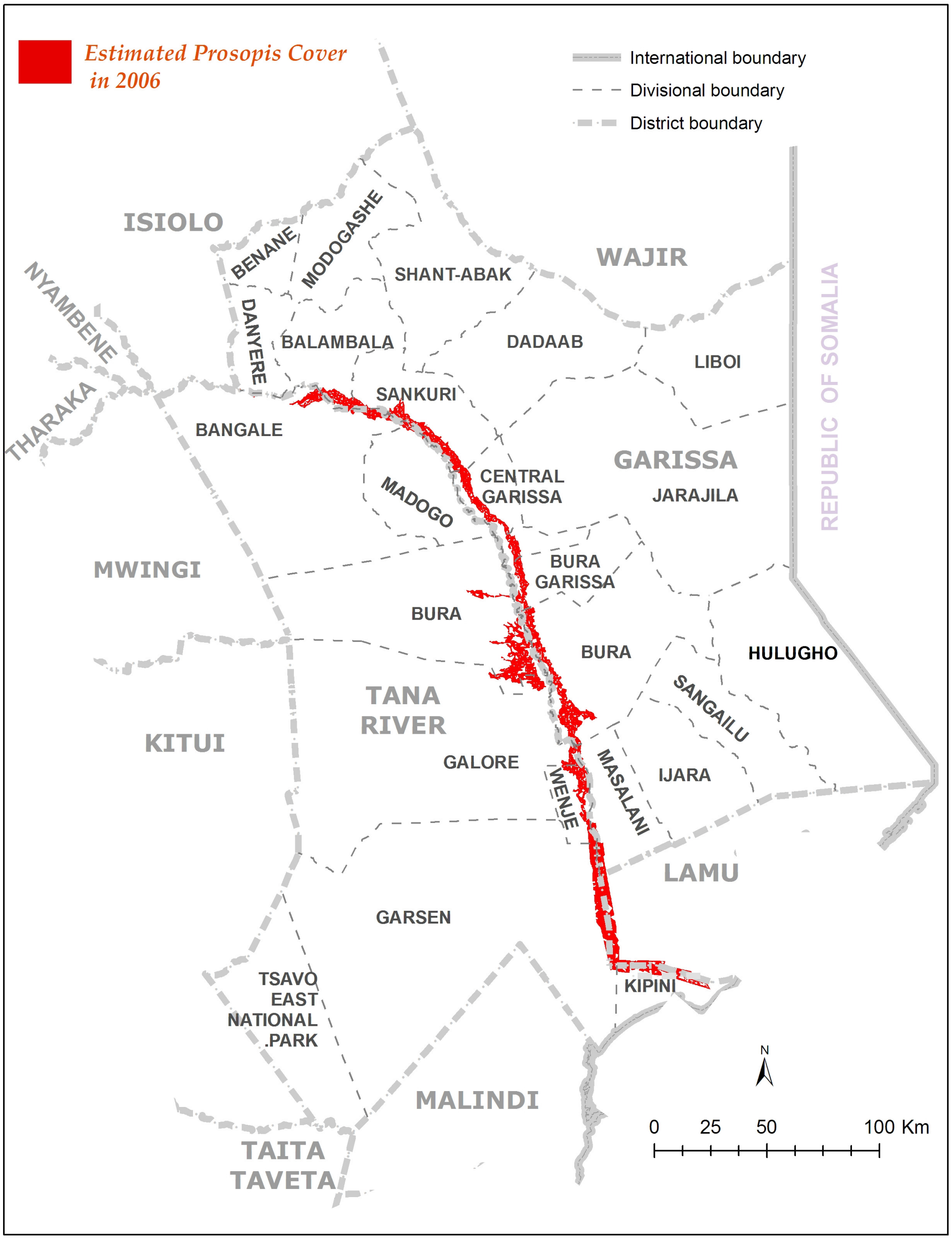


Figure 4.4: Estimated prosopis cover in year 2006 in Garissa

Combining the rasterised shapefiles of *prosopis* coverage and the vectorised shapefiles of the administrative boundaries of the divisions for 2000 and 2006, the study determined the estimated *prosopis* coverage per division (see Table 4.2). The procedure was repeated for the landuse/land cover shapefile (Figure 4.5 below).

The sub-pixel analysis was used in place of the traditional supervised classification or unsupervised classification due to its ability to break down a mixed pixel into components and its transferable signature. It should be noted that at about 167 km spatial coverage per scene, Landsat TM/ETM sensor is usually attractive for its wide coverage which makes it cost effective in regional studies of the nature undertaken here. But, a challenge in its use in discrimination of vegetation species is its relatively medium spatial resolution of 30m x 30m. For large scale studies focusing on small areas, high spatial resolution products like QuickBird imagery provide a suitable alternative. However, the cost is prohibitive for a large area like Garissa County. In the absence of free or less costly high resolution multi-spectral datasets we are confronted with the hard choice between abandoning the estimation and making the most out of this medium resolution imagery.

Accompanying this is the reality that a pixel at this resolution (30m x 30m for multispectral bands) has mixed spectra, thereby raising the mixed pixel problem which dims efficient classification using standard classifiers. But in the knowledge that *Prosopis juliflora* mostly exists in contiguous colonies combined with awareness of technical capabilities of this classification algorithm described in the previous paragraph created possibilities for innovatively overcoming the noted spatial limitations of multi-spectral Landsat images.

For a successful sub-pixel classification, the quantity of training pixels is less important than the quality of the pixels (i.e., pixels that represent nearly 100 percent *prosopis*), but it is important to try to select pixels that represent the full spectral range of *Prosopis*.

Sub pixel classification proved to be a low cost technique providing the opportunity to use medium resolution data as an alternative to high-resolution data .The quality of classification depends on purity of signature and not on number of training areas. Sub pixel classification technique is a time saving technique. It requires only a few numbers of training areas with maximum possible backgrounds as compared to traditional classification techniques.

The study found that a total of 440 square kilometres were newly colonised in Garissa between the years 2000 and 2006. This meant that *prosopis* was colonising on average 73 square kilometres every year between the years 2000 and 2006. This means that if left unchecked, this species will have completely covered the entire County landmass in the next 590 years. This will have huge implications for the thousands of pastoralist and agro-pastoralist families, who will have their livelihoods wiped out as the species will take over pasturelands and farmlands. In addition to this, the species will out-compete all the native vegetation of the County, causing huge biodiversity loss. The thousands of ungulates and their predators will also suffer immensely.

Table 4.2: ***Prosopis*** **coverage/distribution per division**

Affected division	**Total area (in km^2)**	**Area infested by prosopis (in km^2)**			
		Year 2000 (a)	**Year 2006 (b)**	**Areal change (b-a)**	**% change**
Bura	9,076	419	562	143	34
Sankuri	1,751	137	201	64	46
Bangale	6,098	87	134	47	54
Huluqo	549	86	99	12	15
Raya	818	76	93	17	22
Bura Youth	1,301	52	60	8	15
Benane	9,004	56	76	21	36
Balambala	1,878	51	72	21	41
Masalani	1,451	16	21	5	31
Madogo	1,813	14	15	1	7
Danyere	1,095	0.2	0.3	0.05	50
Shanta Abaq	828	107	112	5	5
Central	11,745	202	299	96	48
Total		**1307**	**1748**	**440**	34

The study also found out that Bura division in the County was the most affected by *prosopis* invasion in terms of absolute invasion and colonisation, with a total area of 143km² infested by the species. It also had the most land newly colonised in the six year period between 2000 and 2006, with 143km² taken over. The study also found out that the division least affected by *prosopis* invasion was Danyere division, which saw an areal change of only 0.05km² affected in the same period. The division also had the least area under *prosopis* cover, with only 0.3km² of its total area of 1,095km² infested by *prosopis*.

The fact that Bura division was the most affected in terms of invasion by *prosopis* may be in large part due to the fact that it is also where the first initial planting of *prosopis* by National Irrigation Board was done to combat the then rampant soil erosion. The land in Bura is also most disturbed by the presence of large irrigation schemes, which entail large scale land preparation by clearing the natural vegetation, thereafter leaving the land fallow for long periods of time after crop harvesting. In addition, the irrigation scheme in the early 1990s, resulting in the land remaining fallow for a long period of time, enough for *prosopis* to colonise the land and establish itself.

The division least affected by *prosopis* invasion was Danyere, which is close to 300kms from the initial planting site in Bura. Danyere is characterised by the presence of herbaceous vegetation, which would appear to present competition to the presence of *prosopis*. Key informants interviewed by the study also reported little movement of sheep and goats between Danyere, which is north of Garissa, and the southern division of Bura.

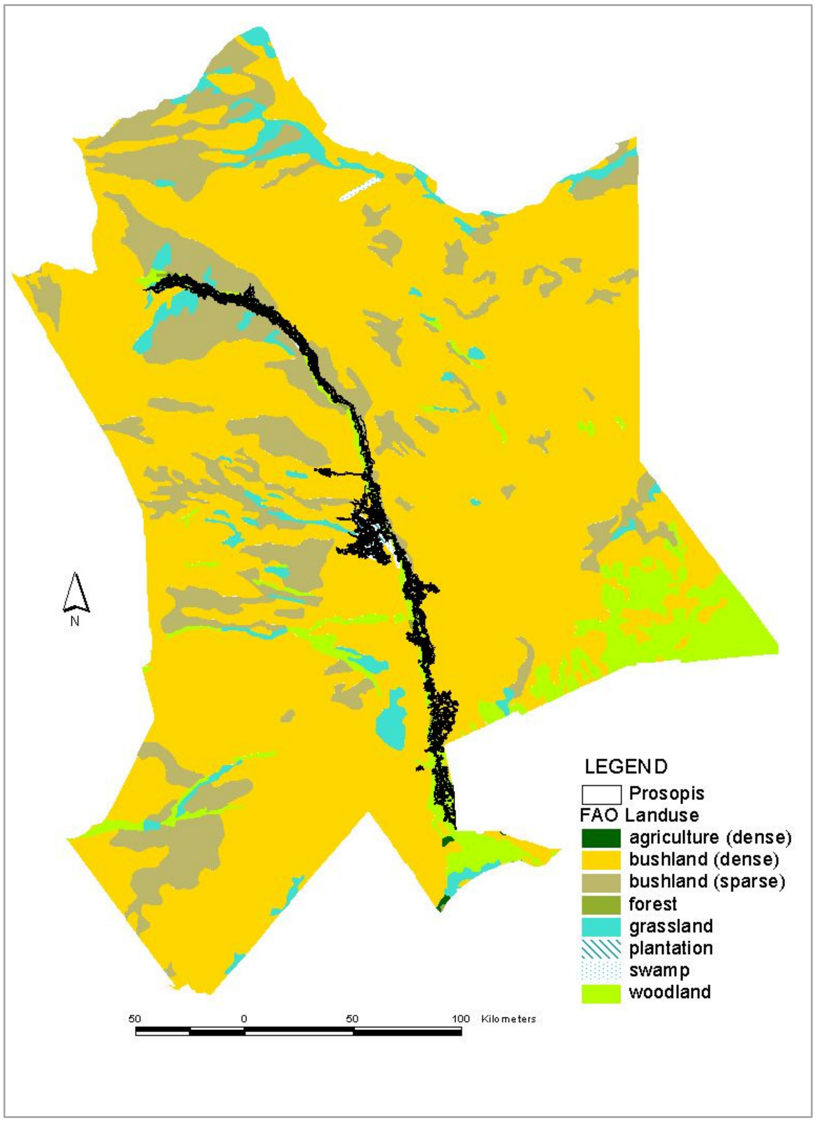


Figure 4.5: Prosopis infestation per land use/land cover classification

The study found out that the riverine forest system of the River Tana was the ecosystem most encroached by prosopis infestation. This is due to the fact that there is plenty of water for the species to establish itself. In addition, the riverine system is an important watering point for the pastoralist community of Garissa and is most times visited by large herds of goats and sheep which need constant watering. The herds are important elements in propagation of prosopis (Choge *et al*, 2002). While seed germination of prosopis can be restricted by a lack of moisture availability to break the hard coat of the seeds, the riverine forests of the River Tana contain highly nutritious alluvial soils, originally from the fertile highlands of Central Kenya. These soils have relatively high soil moisture content due to low water table levels in this area. These conditions are ideal for prosopis seed germination.

Table 4.3: Land-use/land-cover classification of *prosopis* colonized areas in Garissa

Land cover	**Area covered by prosopis in year 2000 (in km^2)**	**Area covered by prosopis in year 2006 (in km^2)**
Riverine system	252	631
Grassland	127	196.67
Bushland/Shrubland	309	393
Swamp	38	42
Woodland	231	319
Forest	22	22
Agricultural	294	144

The main reason for the spread of prosopis northwards from Bura to Garissa town is the goat factor. The main livestock market in the region is located in Garissa town, and many animals are transported overland for the weekly auction. Goats eat the palatable mature pods, and the presence of these animals is usually important for prosopis to be dispersed over long distances and to germinate (Geesing *et al*., 2004). The passage through the digestive tract facilitates germination of the seeds, which are later deposited with the faeces some distance away from the parent plant. The faeces can also serve as fertilizer to seedlings in an initial stage of establishment (Shiferaw, 2004).

The results of the study also suggest that there is a correlation between the amount of spread and the amount of competing plants. In the sites where nothing else or very little had been growing before the invasion of *P. juliflora*, there was a greater tendency of spreading than in sites where previous vegetation existed. Furthermore, in sites where previous vegetation existed, the soil had in general a more coarse texture, which also might be unfavourable to *P. juliflora*, if the stratum is insufficiently deep (Pasiecznik *et al.,* 2001).

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

The results indicate that the level of infestation of prosopis in open grassland areas is relatively low. Dense prosopis stands or thickets away from the rivers, irrigation schemes, roads and settlement areas, which have all been identified as prime prosopis habitats in Garissa have not been witnessed in open savannahs where distribution patterns of prosopis consist commonly of sparsely scattered shrubs. This however does not imply that it does not pose a problem to these dryland ecosystems and those who rely on their productivity, the pastoralists. However, the scattered prosopis vegetation in open grassland savannah may also intensify in the future, as more mature prosopis trees will provide a steadily increasing number of seeds, which may germinate during heavy rainfall and flooding events.

4.4 Community perceptions on *prosopis* invasion and colonisation

4.4.1 Introduction

Peoples' perceptions of invasive species are determined by whether the species meets their socio-economic needs (Pasiecznik, 2001). In the Indian state of Rajasthan, for instance, local peoples' perceptions of the *prosopis* were favourable during the early stages of its introduction. At the time it was a welcome relief from the then imminent fuelwood crisis. Peoples' perceptions changed later as the species' negative attributes become clearer and more pronounced: invasion of fertile farmlands, sharp thorns, suppression of grasses and associated vegetation (Zeila, 2005).

4.4.2 Origin of *prosopis*

The findings indicated that all respondent interviewed for the study were aware of the existence of *Prosopis juliflora* in their environment. *Prosopis* was introduced to Garissa town in 1983. According to the key informants, local tribal leaders were not consulted before the introduction of the species.

Enquiry into the status of prosopis over the last 10 years indicates a general increase in the tree's density, both on communal grazing areas and on individually controlled areas such as homesteads and cultivating fields. The increase of prosopis on 'individual' land was attributed to several factors, including difficulties in controlling the spread of the trees and the dispersal of seed by both livestock and water. Only 3% of the respondents observed that the plant had declined on their land because of their continuous efforts to control it. On community land, however, it was acknowledged that prosopis density had increased tremendously primarily because there were no organized attempts at controlling its spread.

Further, the tendency of livestock to graze and concentrate on the communal grazing fields transported the seeds there through their droppings. Soil fertility was enhanced by livestock droppings, creating good conditions for Prosopis growth. The communal grazing fields are located around the banks of River Tana, where water is readily available, further enhancing the conditions for the growth and proliferation of prosopis. Ground cover of herbaceous species underneath *Prosopis juliflora* stands have decreased on both communal and individually controlled land. *Prosopis juliflora* stands are also thought to cast sufficient shade to suppress undergrowth establishment, while placing high demands on water and nutrient capacities of the soil (Pasiecznik, 2001). These deleterious effects of prosopis on the development of undergrowth are more intense on the communal grazing grounds where the stands are denser.

Different respondent had different perceptions regarding the origins and introduction of the species into their environment. An overwhelming majority of the respondents (69%) indicated that they believed that prosopis was primarily introduced in their environment by foreign organisations (see Table 4.4 below). A significant number of the respondents perceived that animals were the main source of the introduction of the species into Garissa town.

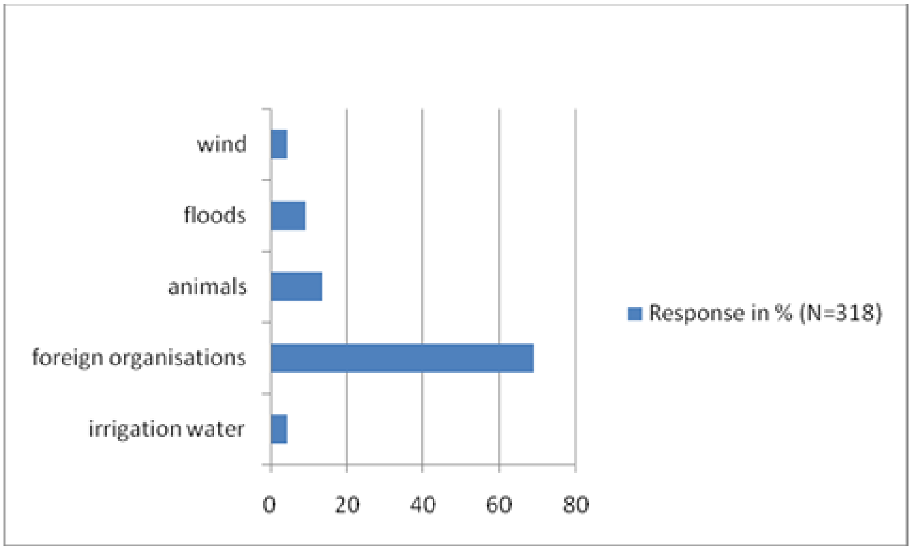


Figure 4.6: Primary sources of introduction of *Prosopis* into Garissa

Although prosopis was not introduced into Garissa by foreign organisations, the pastoralists do not have much regard for political boundaries, hence considering Tana River County as their own. This indicates that most inhabitants of Garissa have situational awareness of their environment and were informed of the massive irrigation scheme in neighbouring Tana River County where prosopis was first introduced.

4.4.3 Degree of invasiveness of the species

Degree of awareness of individuals about the invasiveness of the weed is one of the factors influencing the decision of individuals to be involved in management of prosopis. In this regard, sample individuals were asked about their perception of whether the species was invading and colonising more land.

Ninety two per cent (92%) of the respondents believe that *Prosopis* is a highly invasive plant that was colonising more land and spreading rapidly (see Figure 4.6). They regard prosopis negatively as they believe it to be in competition with their livelihood systems (such as pastoralism). The fact that prosopis tends to be of little use to their livestock in terms of fodder also contributes to this viewpoint.

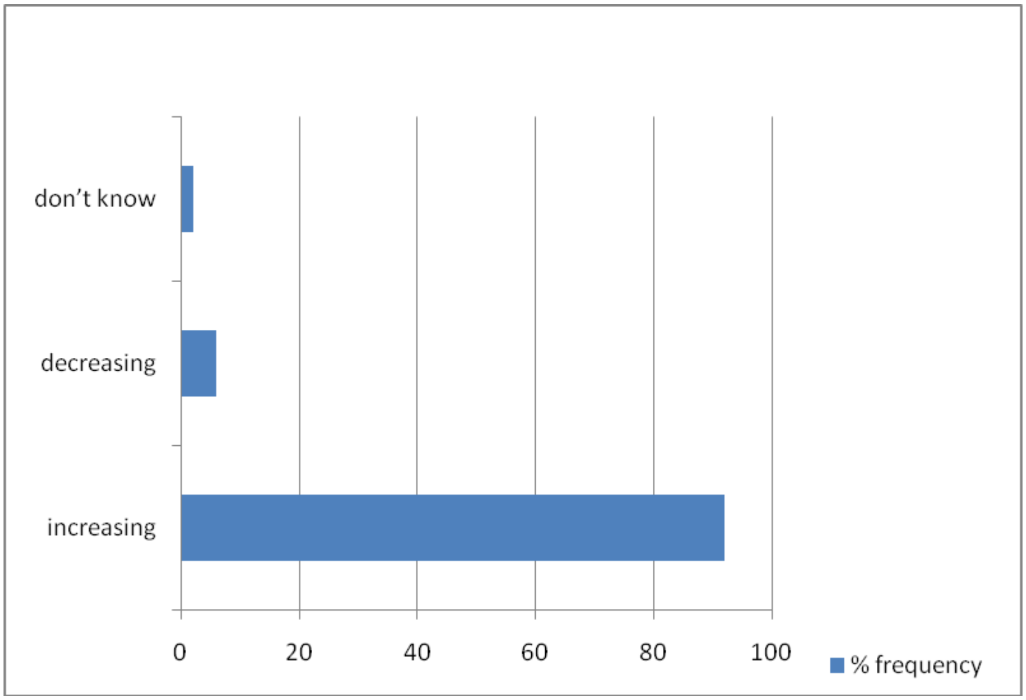


Figure 4.7: Percentages of individual's perception of invasiveness of *prosopis* in Garissa

4.4.4 The effect on indigenous biodiversity

Eighty four per cent (84%) of the respondents indicated that *prosopis*' presence has had a negative effect on the indigenous biodiversity of Garissa (see Figure 4.7). There is widespread belief that that considerable number of plant species have disappeared from Garissa's riverine forest system because of out-competition by *prosopis* for resources such as shade, plant nutrients and water. The respondents believe that prosopis has been preventing young seedlings of the indigenous vegetation from sprouting and establishing themselves.

The Tana riverine system is very important ecologically and economically to the residents of Garissa. A large proportion of the population lives in close proximity to the forest, which provides essential services such as water for the livestock, fodder and other forest products that can be sold in the open markets.

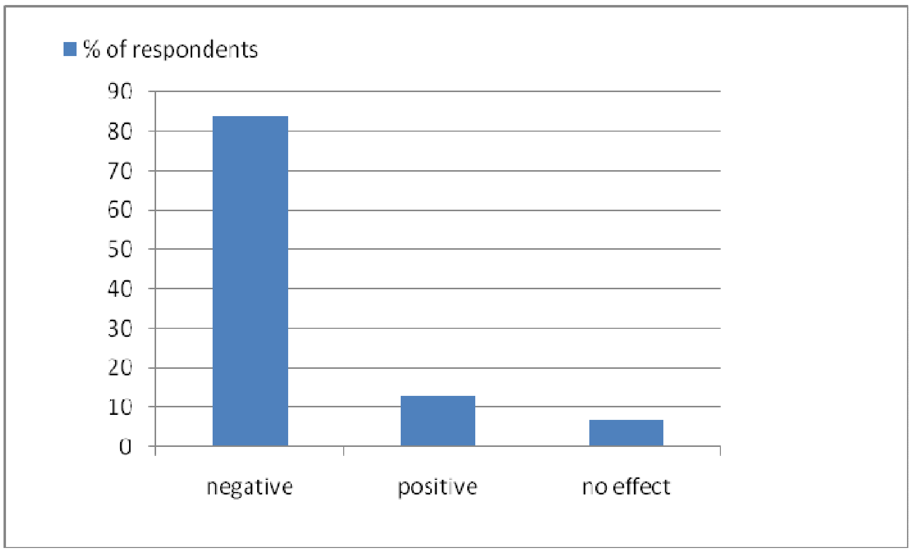


Figure 4.8: Effect of *prosopis* on indigenous biodiversity

Key informants reported that about half a dozen plant species that had 'disappeared' from the area were locally used for grazing and that ground cover of herbaceous species underneath *Prosopis juliflora* stands have decreased on both communal and individually controlled land. The loss of grasses from the area is a most disappointing phenomenon to the local people as they heavily depend on livestock production. According to the key informants plant species that have disappeared in the prosopis infested areas are still existent in the area that is not yet infested.

According to the key informants, several animal species that have traditionally lived in the area have fled because of the dearth of their traditional forage grasses, which is attributable directly to the presence of *prosopis*. Animal species that have migrated from the area include Burchell's Zebras and ostriches.

4.4.5 Effects of *prosopis* on livestock production

Eighty eight (88%) of the respondents indicated that *prosopis* affects livestock production while 12% said it has no effect. The livestock most affected by this were said to be donkeys and goats. Among the respondents who indicated that *prosopis* affects livestock production, the reasons cited are included in the Table 4.7 below, where encroachment of grazing land was ranked first while physical injuries to the animals was ranked the least.

Table 4.4: Effect of *prosopis* on livestock production in Garissa

Effect on livestock production	Ranking (N=327)	
	Freq. scores	Rank
Encroaches grazing lands	224	1
Negative effect on animal health	209	2
Reduces milk production	173	3
Physical injuries to animals	118	4

The key concern of the respondents was that prosopis dries up grazing areas as it consumes a lot of water. They believe that the infestation of prosopis on their grazing land degraded the natural vegetation and both grasses and trees were not growing or not growing sufficiently. Respondents furthermore stated that prosopis depletes the soil of nutrients and that its canopies prevent the sun light from reaching the grazing land. All these end up adversely affecting the productivity of the rangelands and thus the livestock's production.

The respondents reported that prosopis thorns caused a major problem to both livestock and humans. Not only was the chance greater to inflict injury by prosopis thorns than by those of other thorny plants because prosopis branches hang very low to the ground, but the structure of the thorns was reportedly such that it was "rooted inside the branch" making it much stronger and also much harder to get rid of. The respondents also indicated that the thorns were toxic and that the injuries they inflicted cannot be healed with the same remedies that are usually used for injury through thorns. Instead, the locals have found new ways of treating injury by prosopis thorns with prosopis leaves which they grind and then apply to the wound.

During focus group discussions it was reported that, in addition to the physical and physiological impacts of prosopis on livestock health and production, animals perceived by the markets to have fed on prosopis fetched lower prices during the weekly auctions. The main concern for the market stakeholders is that the animal would soon suffer ill-health as a result of the consumption of prosopis pods. In addition, the discussions also reported a decrease in milk production as a result of livestock browsing on prosopis.

Many pastoralist informants also reported dental problems as a result of feeding on prosopis, especially by goats. The loss of teeth is caused by the continuous chewing of the hard, sweet pods, which get stuck between the teeth causing tooth decay, and eventually the death of the animals, as they become unable to graze.

4.4.6 Uses of *Prosopis juliflora*

Although it is an invasive species that is relatively new in the study area, *prosopis* has found some uses among the local community. Sixty one per cent (61%) of the respondents reported using the species in one way or the other. The study established that the most important uses of *prosopis* were ranked in the following descending order: charcoal, fuelwood, and animal fodder (see Table 4.8 below).

Moreover, *Prosopis* is used for fencing and as timber by the construction industry in Garissa, perhaps because of unavailability of other types of trees that served the same purpose. Of interest is the use of *prosopis* for animal fodder, and key informants reported that its use peaks during the dry season. Through field observations in the market centres, it emerged that there is some trade in *prosopis* pods.

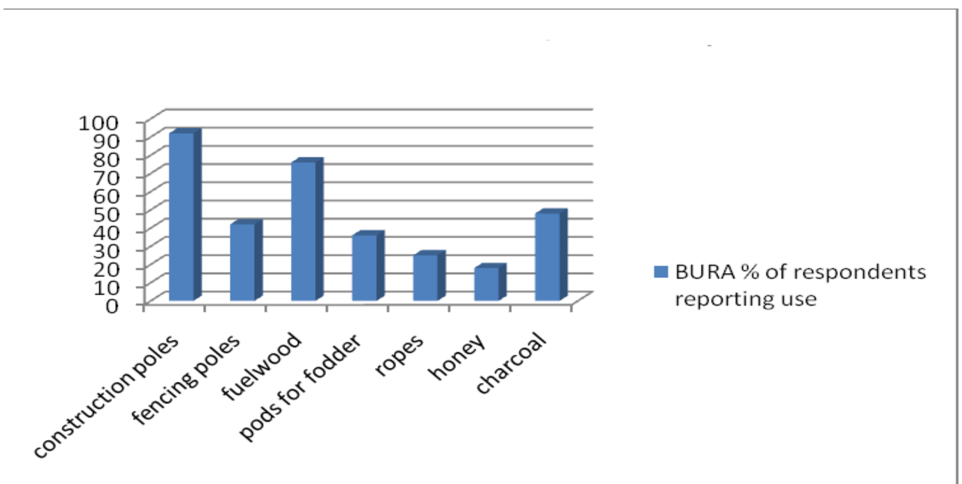


Figure 4.9: Uses of prosopis by households in Bura division, Garissa

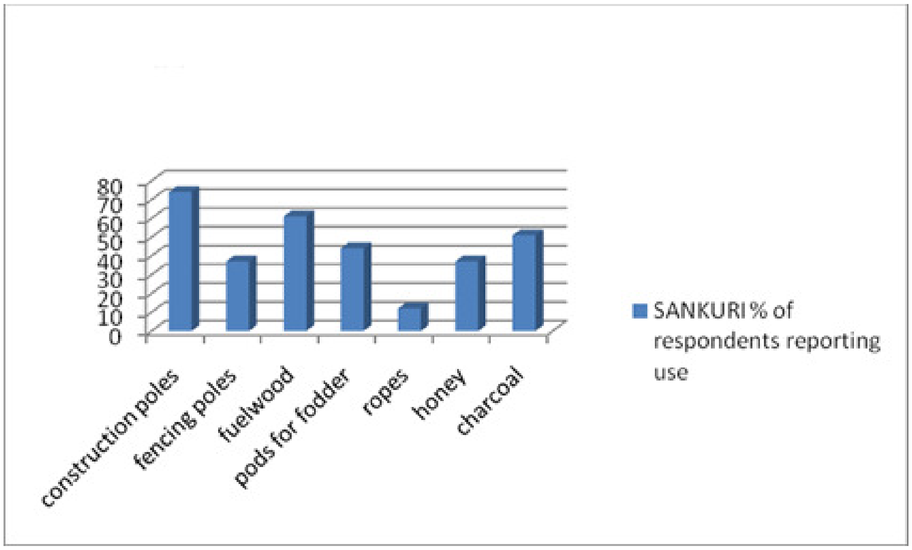


Figure 4.10: Uses of prosopis by households in Sankuri division, Garissa

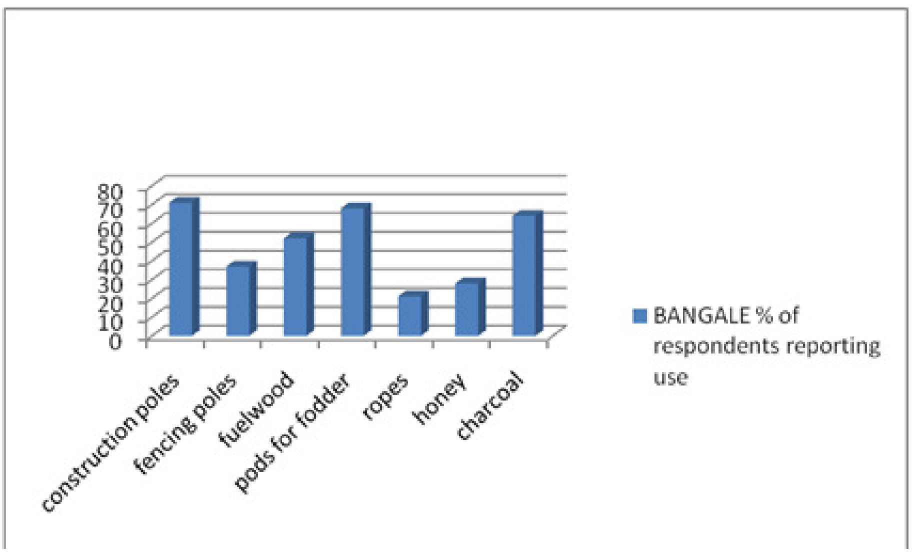


Figure 4.11: Uses of prosopis by households in Bangale division, Garissa

According to the key informants, charcoal makers prefer indigenous trees to *prosopis*, as the charcoal made from indigenous trees is better in quality than *Prosopis* and fetches a higher price.

More intensive harvesting of prosopis products are hampered by many factors, including laws that criminalise the movement and sale of forest products. In addition, prosopis branches have dangerously strong thorns, reputed to be poisonous, that make harvesting difficult. The tree itself is a hardwood species, meaning it wears down simple cutting implements.

Table 4.5: Comparison of prosopis products use in the three divisions in Garissa

Use	Division reporting highest use	Comment
Construction poles	Bura (92%)	Initial planting site, hence has the oldest prosopis trees with the best proportions and girth for construction use; connected by tarmac road to Garissa town, main market
Fuelwood	Bura (76%)	Has the oldest trees with enough biomass for charcoal production; connected by tarmac road to Garissa town, main market
Pods for fodder	Bangale (68%)	Has the largest concentration of livestock in the County (DLPO Garissa, per comm.); pods used as dry season fodder for goats and sheep
Charcoal	Bangale (64%)	Bangale is on the main Garissa-Nairobi highway; many sellers target wayfarers buying the charcoal for onward sale or use in Nairobi

A gender difference was found regarding harvesting of fuelwood. Women in Bura harvested significantly more fuelwood than men (chi=7.64; significance.006). Many of the women respondents acknowledged that prosopis has greatly reduced their fuelwood burden. Because the distances to fuelwood sources are much shorter, more trips can be made with less effort. An additional advantage is that prosopis fuelwood burns well even when wet.

Table 4.6: Statistical relationships between respondents' characteristics and the value of prosopis products harvested

Attribute * Product	Chi-square value	Significance
Gender * Fencing poles	.026	.567
Gender * Construction poles	.068	.593
Gender * Fuelwood	7.464	.006
Gender * Pods	.234	.412
Gender * Ropes	.398	.362
Gender * Honey	.673	.298
Gender * Charcoal	.139	.595
Village * Fencing poles	.413	.937
Village * Construction poles	1.742	.628
Village * Fuelwood	.977	.807
Village * Pods	.538	.910
Village * Ropes	2.870	.412
Village * Honey	8.573	.036
Village * Charcoal	3.536	.316
Age * Fencing poles	3.818	.431
Age * Construction poles	.760	.944
Age * Fuelwood	3.045	.550
Age * Pods	7.576	.108
Age * Ropes	2.496	.645
Age * Honey	2.640	.620
Age * Charcoal	5.105	.277
Education * Fencing poles	.354	.950
Education * Construction poles	2.305	.512
Education * Fuelwood	1.574	.665
Education * Pods	1.585	.663
Education * Ropes	3.563	.313
Education * Honey	4.225	.238
Education * Charcoal	1.431	.698
Occupation * Fencing poles	10.821	.094
Occupation * Construction poles	2.71	.843
Occupation * Fuelwood	5.296	.506
Occupation * Pods	2.049	.915
Occupation * Ropes	4.481	.612
Occupation * Honey	7.350	.290
Occupation * Charcoal	6.028	.420

4.4.7 Methods used to control *prosopis* by the community

The study found out that eighty one percent (81%) of the respondents attempted to control *prosopis* spread in their land by burning the tree down in the hope that this will prevent re-growth and re-colonisation. Clearing and uprooting were the next most commonly used techniques reported by 30% and 28% of the respondents respectively, while the least mentioned technique was the use of spent fuel from the Kenya Power and Lighting Company diesel power generating station in Garissa, which was applied at the base of the tree.

Table 4.7: Techniques used by pastoralists to control *prosopis* in Garissa

Technique	**Frequency scores (N=321)**	**% Scores**
Burning	263	81
Clearing	96	30
Uprooting	89	28
Cutting and pouring spent fuel from KPLC plant	13	4

Minimum efforts to control the *Prosopis juliflora* problem have been undertaken at the group level. In 2007, the local chief and elders of Bura mobilized the community, including women and youth, to remove *Prosopis juliflora* from communal areas in order to open up land for cultivation at the Bura Irrigation Scheme. After clearing, a lottery system was to be applied to allocate the reclaimed land, with each household to receive a between 1 and 8 acres. While the community successfully cleared *Prosopis juliflora* from parts of the area, the project was disrupted by the onset of rains. That year the Tana River burst its banks and changed course, flooding the entire cleared area. The effort was abandoned and *Prosopis juliflora* has since re-colonized the area.

Survey respondents answered questions related to the costs of these control activities. Some people responded in terms of money spent to hire labour, while others provided information about the amount of time spent in clearing and uprooting trees and seedlings. These time estimates were translated into labour costs through a standard cost for casual labour of 50Ksh/6 hour day. Results are presented in monetary terms in Table 4.12. Overall, the average cost per respondent was Ksh 6,232 per year in Bura where the invasion is high and Ksh 1,222 per year in Bangale where the invasion has been less severe.

Table 4.8 Individual labour costs for controlling prosopis on own land

	Bura (n=133)		**Bangale (n=83)**	
Cost	Average value (Ksh / year)	Standard deviation around mean (Ksh / year)	Average value (Ksh / year)	Standard deviation around mean (Ksh / year)
Cost of management /control on individual land	6,242	1,189	1,221	684

4.5 Managing prosopis: a framework for discussion

The introduction of exotic species in fragile ASAL environments can have devastating effects on species and ecosystems, causing a direct threat to the native vegetation. In the dryland regions of Kenya, the state of knowledge, design and appropriate practices regarding prosopis management options is very limited, principally due to an overall dearth of reliable field data, systematic research and local assessments that could work as a basis for the design of appropriate management measures. Whilst this study shows that pastoralist communities in Garissa have tried to manage and eradicate the species within their immediate surroundings there has been little or no action taken by government or the private sector to date that may have covered a wider area or taken a more coordinated management approach. In this section this study will provide ideas for discussion on how best to combat prosopis.

4.5.1 Land tenure reform

One of the biggest problem facing communities trying to manage the invasive alien species has been the lack of appropriate land tenure systems that can provide the incentive for the general populace to control the spread of the species. Garissa County is perhaps an outstanding example of the argument of the tragedy of the commons: the land has not been subdivided and adjudicated, thus providing for non-titling and "non-ownership" of the land. The land is said to be Trust Land, held in trust by the local government authority for the people.

Effectively, this means that everyone views the prosopis menace as the problem of "everyone", thus avoiding direct action aimed at controlling the rapid advance of the species. The government needs to make a determined effort to control the species through providing for the appropriate land tenure reforms.

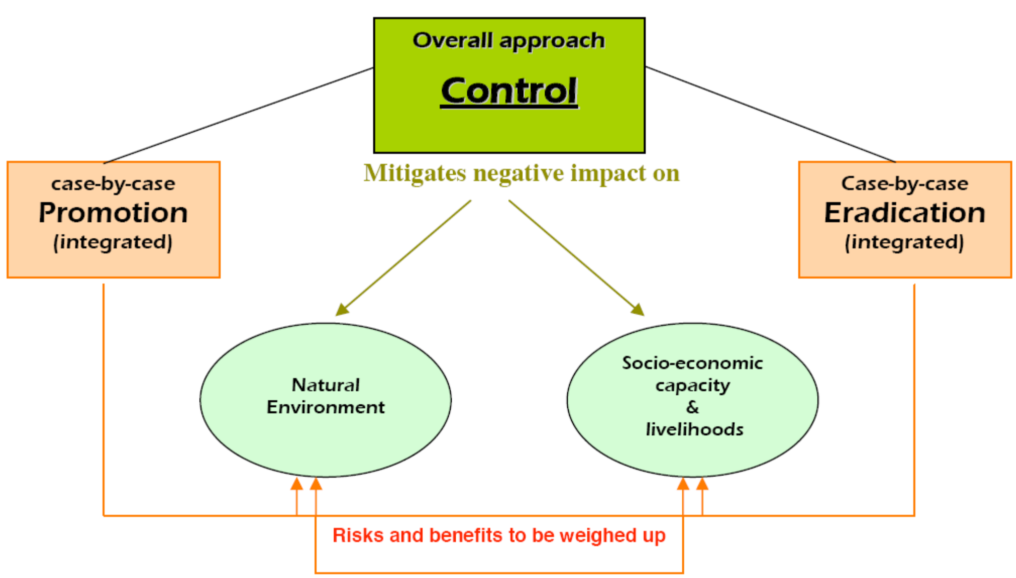
4.5.2 Eradication or management?

The biggest dilemma facing the communities in areas affected by prosopis colonisation is whether to eradicate the species or find a way of managing the spread. It is best to consider best bet practices from other countries in the region, such as Sudan. At some point the government of Sudan went on a massive eradication mission, especially in and around the giant irrigation schemes in the country, incurring expenses to the tune of several million dollars. However, the success rate has been modest even when the root system is removed, as Prosopis is spread repeatedly via animal droppings, water or by wind storms (Zeila and Bashir, 2005).

In the light of overwhelming evidence showing that prosopis eradication is virtually impossible at the current level of technological and scientific advancement, it is perhaps time to surmise that spending on eradication programs will be a complete waste of time and resources, and that it is better to spend resources in innovating new ways of using the species for economically rewarding enterprises.

4.5.3 Differentiated species control regimes

Even within the ASAL ecosystems, there are regions that are more fragile than the other or those that have more values in terms of environmental services and economic strategic value, such as irrigated areas, riverine ecosystems. It is therefore essential that spread control measures are put in place to decrease unwanted invasion of prosopis into these regions. In areas such as these, it will be imperative to institute eradication measures as these areas constitute lifeline zones for the region's economy. The control regime proposed in this study is reflected in the figure below.



CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The study shows that *prosopis* represents a real threat to the local species, as its cover is increasing, as observed during the 6-year comparison period, during which it increased by 440km^2.

The study noted that the general consensus among the pastoralist community of Garissa County is that *prosopis* is a species detrimental to the continued sustainability of their main mode of livelihood, that is, pastoralism. The study also determined that no significant measures have been put in place, either by government agencies or non-governmental organisations, to control the spread of the species.

In addition, the study also found out that beneficial uses for the species have not been properly optimised and promoted. Indeed, from discussions with key informant interviews, the study established that there are policy bottlenecks to the actual enjoyment of the beneficial uses of *prosopis*.

5.2. Conclusions

Thirty years after Prosopis *juliflora* was introduced into the rangelands of Garissa it is now well established and threatens to render non-functional watercourses and swamplands that form critical dry season pastures and farmlands. Pastoralists in Garissa are generally of the opinion that it is best to eradicate it, not least because its benefits are being far outweighed by its undesirable properties. According to these communities, their primary livelihood options of farming and livestock keeping are threatened by the unchecked expansion of the invasive alien species.

Individuals' perceptions of the invasive *Prosopis* are influenced by their weighting of the costs against the benefits of living with the species. This calculus is expressed in their overwhelming demand for eradication. Kenya is not the only country confronted with the problem of *Prosopis juliflora* invasion. There is considerable opportunity to learn from other countries where this menace has been turned into a resource. In India, the Gujarat State Forest Development Corporation, the Gujarat Agricultural University, Anand, and the Vivekenand Research and Training Institute, Mandvi-Kachchh have developed programs for the collection, processing and marketing of various products from different parts of *Prosopis juliflora*, while providing employment to the rural poor.

5.3 Recommendations

- The study was able to adapt a methodology, using GIS techniques, to map the extent of *prosopis* coverage in Garissa County, at a reasonably low cost. This technique can be scaled-out to put in place a programme for mapping out all *prosopis*-infested areas in the rest of arid and semiarid Kenya. The results of this mapping exercise can be used by government agencies responsible for development coordination in northern Kenya to delineate problem areas and institute programmes and projects that will seek to first of all arrest the spread of *prosopis*, while at the same time creating avenues for wealth and employment creation.
- There is need to put in place commercially-oriented prosopis control programmes to deal with the increasing *prosopis* biomass. This should be

taken up by government institutions responsible for managing arid lands such as Arid Lands Resource Management Project. It has been proved elsewhere that alien invasive species are hazardous to the local environment.

- Communities need to be sensitized on the importance and potential uses of *prosopis* products. This will contribute to the communities changing their perceptions and consider the tree as a resource.

- The usage of *prosopis* as an economic resource has been generally neglected, yet *prosopis* has potential to support livelihoods. It produces high quality charcoal and its heartwood is strong and durable. It branches can be used as fencing posts, while its pods which are high in protein and sugars may be important fodder for livestock when combined with other fodders.

- There is need to promote charcoal production from *prosopis* wood. Charcoal is one of the main 'industries' in dryland Kenya, with some estimates indicating that the industry is worth KSh 40 billion. *Prosopis* charcoal has high calorific value and the wood is plentiful and easily available. Utilisation for charcoal will reduce the pressure on important indigenous tree species such as Acacia, whose existence is threatened by charcoal burning activities. This utilisation will also free farmlands and pasturelands for other productive use.

- There is need to promote the use of efficient charcoal production kilns when producing *prosopis* charcoal. Charcoal is mainly produced using the traditional earth kilns (TEKs), which have low recovery rates of about 5%. Communities can explore the use of efficient kilns like the Casamance kiln from Senegal and the Half Orange kiln.

- Government policies regarding charcoal production and movement need to be streamlined to reflect the role of *prosopis* in charcoal making. There is, therefore, need to legitimise and promote trade in *prosopis* charcoal.

Land tenure, in terms of land adjudication and titling, is a problem with most of the land classified as communal/trust land, under the care of the government. Land adjudication has generally not been done. There is need to address this issue urgently.

For further studies, this study recommends further research into the:

- Usefulness of *prosopis* in relation to intercropping with horticultural crops (the main agricultural industry in the Garissa). This will be of great interest to the dryland farmers of Garissa County who wish to farm along the Tana but are prevented from doing so by the massive presence of the species along the river.
- The effect of *prosopis* on soil productivity so as to determine whether the species has any role in biological nitrogen fixation and thus can be used to enhance soil fertility in the depleted low fertility soils of northern Kenya.
- There is also a need for research on the exact mechanism (chemical or physiological) which makes *prosopis* out-competes indigenous vegetation. This may be useful in initiating plant breeding programs that will seek to reduce the out-competition tendencies while maximising on its positive aspects.

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7 APPENDICES

7.1: Researcher Administered Household Questionnaire

Respondent's name: _____________Age: _______Sex:_________

Date:__________________ Location: _____________________

Size of land (acres): _________________ Occupation: ____________

Q1: Are you aware of the existence of *Prosopis juliflora*?

Yes No

2. Where is this species found?

(a) Own land (b) community land (c) government land

2. Does it grow in your area?

Yes No

Q2: Do you know when *prosopis* was first introduced into Garissa region?

Yes No

Q3: Who introduced *prosopis* in Garissa region?

1. Irrigation water from the Tana
2. Foreign organisations
3. Animals
4. Flooding
5. Wind

Q4: Has the density of prosopis increasing or decreasing in the last 5 years?

1. Increasing
2. Decreasing

3. Don't know

Q5: How would you describe the effect of *prosopis* on your pasturelands?

1. Positive effect
2. Negative effect
3. No effect

Q5: How would you describe the effect of *prosopis* on your farmlands?

1. Positive effect
2. Negative effect
3. No effect

Q6: Please rank in order of importance what you think is the effect of *prosopis* on livestock production in your area.

Effect	*Rank*
Dental condition in goats	
Encroaches grazing lands	
Physical injuries to animals by thorns	
Reduces milk production	
Declining pasturelands	

Q7: Does *prosopis* have negative implications for human health?

Yes No

If yes, please rank in order of importance what you think is the effect of *prosopis* on human health in your area?

Effect	*Rank*
Thorn pricks, itching	
Blindness	

Tetanus	

Q8: Do you use *prosopis* in your area? Yes No

If yes, please rank in order of importance the uses of prosopis in your area.

Uses	*Rank*
Timber	
For shade	
For fencing	
Pods for livestock	
Honey making	
As fuelwood	
For charcoal	

Q11: In your experience, what techniques are being by the community to control the spread of *prosopis*? (Please tick against the choices)

Control method	*Tick*
Burning	
Clearing	
Uprooting	
Cutting and pouring spent fuel from KPLC plant	

Q12: In your opinion, are the projects and programmes put in place by government and other players to control the spread of prosopis effective?

1. Effective
2. Not effective

If "Not effective", why?

7. 2: Key Informants Interview

Introduction

I am a Masters student from Kenyatta University. I am conducting research to determine the spread of the invasive species *Prosopis juliflora* in Garissa County. The information you provide will be treated in strict confidence and will only be used for purposes of submitting my thesis for examination to the University.

I would like to ask you some questions relating to the spread of *prosopis*. The interview will take about 30 minutes.

Name:	Date:	Area
Affiliation:	Time discussion started:	Time discussion ended:
Profession:	Female/Male:	

1. Background information

a) How long have you worked with your current organisation?

b) What are the issues of primary importance to the community in as far as prosopis invasion is concerned? (*Please rank them in order of importance*.)

2. Prosopis invasion and colonisation

a) Please list the effects of prosopis invasion and colonisation of land in Garissa County, with reference to effect on native biodiversity, livestock production, human health, livelihoods.

b) What is your opinion regarding the involvement of the Garissa community in prosopis management programs? Is the involvement adequate?

c) What technical innovations have been introduced by organisation working in the County in the context of prosopis management?

d) Do you think that there is a strong commitment by the local authority in combating the spread of *prosopis*?

e) Are there any trainings that were undertaken by NGOs for community members in order to improve their capacity to manage the spread of prosopis?

f) How does the community manage the problem of prosopis invasion of farmlands and pasturelands?

g) What challenges do you think the community is facing in its fight against prosopis? Technical? Policy? Legal? What recommendations would you make to resolve this?

h) Are there any community-level association or organisation established to specifically fight against prosopis?

7 3: Work-plan

Activities	January 2009				April 2009				Nov 2010		Jan 2011	
Conduct pilot test												
Revise instruments												
1st field research			■									
Partial data analysis		■		■								
Fieldwork with supervisors					■	■						
2nd field research							■	■				
Data analysis									■	■		
Reporting											■	■

7.4. Summarised Survey-based data (SPSS derived): Correlation tests

		What is your main livelihood?	How would you describe effect of prosopis on your land?
What is your main livelihood?	Pearson Correlation	1	.809(**)
	Sig. (2-tailed)	.	.000
	N	290	290
How would you describe effect of prosopis on your land?	Pearson Correlation	.809(**)	1
	Sig. (2-tailed)	.000	.
	N	290	290

There was strong positive Pearson correlation coefficient between the livelihood system and the perceptions on effect of prosopis ($r = 0.809$ and $p = 0.000$) meaning there a statistical significance in the relationship.

7.5. Summarised Curriculum Vitae of Researcher

Name: Abdi Zeila Dubow

P O Box 16109 – 00100 Nairobi GPO **Cell**: 0723 139 480 or 0722 363 321
Email: azeila@csdikenya.org

2000 – 2003 **Kenyatta University, Nairobi**
Bachelor of Environmental Science

- Second Class Hons. Upper Division

1994 – 1998 **Garissa High School**
Kenya Certificate of Secondary Education (KCSE)

- B (Plain)

1986 – 1993 **Jaribu Primary School, Garissa**
Kenya Certificate of Primary Education (KCPE)

- 502 points (out of 700)

Employment Record

Aug 2010 – Dec 2010 **Alliance for a Green Revolution in Africa (AGRA)**
Soil Health Consultant (Monitoring and Evaluation)

- Oversee collection of baseline surveys for soil health projects
- Review monitoring and evaluation tools in use in Pillar 1 and Pillar II countries and develop user-friendly and systematic data collection instruments

August 2009 – June 2010 **Centre for Sustainable Development Initiatives**
Programmes Coordinator

- Overall planning and coordination of CSDI programs and projects, with leadership
- for wide range of administrative and management support services;
- Review of plan of work and budgets of CSDI programs and projects;
- Budgets and expenditure tracking;

Jan 2004 – Dec 2006 **World Agroforestry Centre (ICRAF)** **Nairobi**
Project Officer, Agroforestry for Livelihoods Improvement in the Drylands (ALID) Project

- Responsible for managing the implementation of the ALID Project, a 2-year pilot project jointly funded by ICRAF and Arid Lands Resource Management Project (ALRMP) of the Office of the President;

Languages
Somali, Arabic, English, Swahili

References

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Mohamed Awer, Country Director, WWF, ACS Plaza, Lenana Road, Nairobi: Email mawer@wwfearpo.org Cell: 0729 999 251