EFFECTS OF SOIL CHARACTERISTICS AND DISTURBANCE ON FLOODPLAIN VEGETATION IN UPPER TANA RIVER, KENYA

By

Omari Joyce Kanini, B. Ed (CUEA), M. Sc (UoN)

Reg. No. I80/52697/2018

School of Biological Sciences
University of Nairobi

A Thesis Submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy (PhD) in Plant Ecology

University of Nairobi

January, 2020

DECLARATION

I, Joyce Kanini Omari hereby declare that this thesis is my original work and has not been presented for award of a degree in any other University.

Signature…………………………………………… Date………………….

Registration No. I80/52697/2018

This thesis has been submitted with our permission as the supervisors.

Prof. Nathan Gichuki

School of Biological Sciences

University of Nairobi

Signature…………………………………………… Date………………….

Prof. John Mworia

School of Pure and Applied Sciences

Meru University of Science and Technology

Signature…………………………………………… Date………………….

Dr. Cosmas Mligo

Department of Botany

University of Dar es Salaam

Signature.. Date...........................

ACKNOWLEDGEMENTS

I thank the Almighty God for granting me life, good health and ability to complete this thesis. I am grateful to all the people who supported me through prayers, technical support and sharing information. I single out the director and the staff of School of Biological Sciences for their encouragement. Special gratitude goes to my supervisors, Prof. Nathan Gichuki, Prof. John Mworia and Dr. Cosmas Mligo for tirelessly guiding me in my PhD thesis. Their invaluable advice and useful suggestions broadened my understanding and greatly enriched my knowledge.

My sincere appreciation goes to Organization of Women in Science for the Developing World (OWSD) for facilitating this research through funding. I also appreciate the staff of Kenya Agricultural Research Institute at Muguga, particularly Mr. Wakaba, for their cooperation during analysis of soil samples; Mr. Musembi and Mr. Patrick Mutiso for assisting in the collection and identification of plant species. Mr. Thuranira of National Agricultural Research Laboratories for helping with the statistical data analysis.

I am greatly indebted to my parents, siblings and friends for their prayers especially when the going got tough. Last but not least, special thanks go to my children, Kemunto, Ong’ombe, Mbeki and Gichogo for their unwavering support throughout the period of study and writing of this thesis. Their prayers, patience and understanding went a long way in ensuring successful completion of this study.

DEDICATION

To my late husband, Omari Gichogo, my source of inspiration, till we meet again in the heavenly kingdom...To my children: Kemunto, Ong'ombe, Mbeki and Gichogo, for their prayers, support and forgiveness for being an absent parent for a long time... To my parents, for imparting in me God's wisdom that can never fail, and finally, to all those in pursuit of academic knowledge... commitment and determination are key.

TABLE OF CONTENTS

DECLARATION i

ACKNOWLEDGEMENTS ii

DEDICATION iii

TABLE OF CONTENTS iv

LIST OF TABLES x

LIST OF FIGURES xv

ABSTRACT xxi

PUBLISHED ARTICLES FROM THIS RESEARCH WORK xxiii

CHAPTER ONE: INTRODUCTION 1

- 1.1Characteristics of Savanna ecosystems 1
- 1.2 Drivers of plant community dynamics 3
  - 1.2.1 Climate variability 3
  - 1.2.2 Bush Encroachment 4
  - 1.2.3 Livestock 4
  - 1.2.4 Non-indigenous Invasive Species 5
  - 1.2.5 Seasonal river flooding 6
- 1.3 Conceptual framework 7
- 1.4 Justification 8
- 1.5 Research Questions 10
- 1.6 Main objectives 10
- 1.7 Thesis structure 11

CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS 12

- 2.1 The Study Area 12
- 2.2 Research Plan 16
- 2.3 Sampling procedure 16
  - 2.3.1 Vegetation sampling 16
  - 2.3.2 Sampling and laboratory analysis of soil samples 17
- 2.4 Experiment 1: Effects of herbaceous defoliation and cultivation on emergence, survival and growth of *A. tortilis* and *P. Juliflora* seedlings on and off the floodplain 17

2.5 Experiment 2: Effects of site characteristics and soil treatments on the emergence, survival and biomass of *Acacia tortilis* and *Prosopis Juliflora* seedlings 17
2.6 Data Analysis 18
2.6.1 Analysis of vegetation data 18
2.6.2 Analysis of soil data 18
2.6.3 Analysis of experimental data 18
CHAPTER THREE: VEGETATION COMPOSITION, ABUNDANCE AND SPECIES RICHNESS 20
3.1 Introduction 20
3.2 Objectives 23
3.3 Materials and Methods 23
3.3.1 Data analysis 25
3.4 Results 25
3.4.1 Vegetation abundance and richness inside and outside the floodplain 25
3.4.1.1 Variation in tree species richness and density 25
3.4.1.2 Variation in shrub species richness and density 29
3.4.1.3 Variation in woody species sapling richness and density 32
3.4.1.4 Variation in woody species seedling richness and density 35
3.4.1.5 Variation in forb richness and density 39
3.4.1.6 Variation in perennial grass species richness and density 41
3.4.1.7 Variation in the basal areas of trees 42
3.4.1.8 Variation in the canopy covers of trees 44
3.4.1.9 Variation in the importance value of trees 46
3.4.2 Vegetation abundance and richness among land use types 48
3.4.2.1 Variation in tree species richness and density among land use types 49
3.4.2.2 Variation in shrub species richness and density among land use types 52
3.4.2.3 Variation in richness and density of woody species saplings among land use types 55
3.4.2.4 Variation in density and richness of woody species seedlings among land use types 59
3.4.2.5 Variation in richness and density of forb species among land use types 62
3.4.2.6 Variation in richness and density of perennial grass species among land use types 66
3.4.2.7 Variation in tree basal area among land use types 67
3.4.2.8 Variation in tree canopy covers among land use types 69
3.4.2.9 Variation in tree importance value among land use types 73
3.5 Discussion 76

3.5.1 Overall vegetation dynamics inside and outside the floodplain 76
3.5.2 Dynamics of the vegetation found only inside the floodplain 77
3.5.3 Dynamics of the vegetation found only outside the floodplain 78
3.5.5 Dynamics of vegetation based on land use types...81
3.5.6 Prosopis juliflora invasion and indigenous plant communities 86
3.6 Conclusion 87
CHAPTER FOUR: TREE SPECIES DISTRIBUTION IN RELATION TO SOIL PROPERTIES AND LAND USES 89

4.1 Introduction..89
4.2 Objectives 91
4.3 Materials and Methods...91
4.3.1 The study area 91
4.3.2 Vegetation and Soil sampling procedures...92
4.3.3 Laboratory analysis of soil samples..93
4.3.3.1 Determination of moisture content and bulk density..93
4.3.3.2 Determination of pH 93
4.3.3.3 Determination of organic carbon 94
4.3.3.4 Determination of total nitrogen..94
4.3.3.5 Determination of phosphorus...95
4.3.3.6 Determination of exchangeable cations 96
4.3.3.7 Determination of Cation Exchange Capacity (CEC) 96
4.3.4 Statistical analysis of Soils...96
4.4 Results...97
4.4.1 Variation in soil characteristics inside and outside the floodplain 97
4.4.1.1 Bulk density (g/cm^3) 97
4.4.1.2 Moisture content (%) 98
4.4.1.3 Alkalinity/Acidity test (pH) 98
4.4.1.4 Organic carbon (%)...98
4.4.1.5 Nitrogen (%) 99
4.4.1.6 Phosphorus concentration (ppm) 99
4.4.1.7 Potassium concentration (ppm)..99
4.4.1.8 Magnesium concentration (ppm) 100
4.4.1.9 Calcium concentration (ppm) 100
4.4.1.10 Cation Exchange Capacity/CEC (centmoles/kg) 101
4.4.2 Variation in soil characteristics across land use types 102
4.4.2.1 Bulk density (g/cm^3) 102

4.4.2.2 Moisture content (%) 102
4.4.2.3 Alkalinity/Acidity (pH) 103
4.4.2.4 Organic carbon (%) 103
4.4.2.5 Nitrogen (%) 103
4.4.2.6 Phosphorus concentration (ppm) 104
4.4.2.7 Potassium concentration (ppm) 105
4.4.2.8 Magnesium concentration (ppm) 105
4.4.2.9 Calcium concentration (ppm) 105
4.4.2.10 Cation exchange capacity/CEC (centmoles/kg) 106
4.4.3 Gradient analysis of vegetation and soil data using Canonical Correspondence Analysis 107
4.4.3.1 CCA of tree species and soil data from inside the floodplain 108
4.4.3.2 CCA of tree species and soil data from outside the floodplain 112
4.4.3.3 CCA of tree species and soil data in wildlife conservation areas 116
4.4.3.4 CCA of tree species and soil data from livestock grazing areas 121
4.4.3.5 CCA of tree species and soil data from irrigated agricultural areas 124
4.5 Discussion 129
4.5.1 Variation in soil characteristics 129
4.5.2 Influence of soil characteristics on tree species distribution 131
4.6 Conclusion 135
CHAPTER FIVE: EFFECTS OF DEFOLIATION AND CULTIVATION ON GROWTH PERFORMANCE OF *A. tortilis* AND *P. juliflora* 137
5.1 Introduction 137
5.2 Objectives 139
5.3 Materials and methods 140
5.3.1 Study site 140
5.3.2 Experimental design 140
5.3.3 Data analysis 143
5.4 Results 144
5.4.1 Emergence of seedlings inside and outside the floodplain 144
5.4.2 Survival of seedlings inside and outside the floodplain 147
5.4.3 Effect of defoliation on shoot growth inside and outside the floodplain ... 152
5.4.4 Effect of defoliation on taproot growth inside and outside the floodplain ... 156
5.4.5 Effect of defoliation on biomass inside and outside the floodplain 160
5.5 Discussion 166
5.5.1 Effect of floodplain on emergence, survival and growth of seedlings 166

5.5.2 Effect of defoliation and cultivation on emergence, survival and growth of seedlings....168
5.5.3 Relevance of results to management of *P. juliflora* and promotion of *A. tortilis*.171
5.5.4 Relevance of results to modeling/predicating impacts of climate change....173
5.6 Conclusion....176
CHAPTER SIX: EFFECTS OF SITE CHARACTERISTICS AND SOIL TREATMENTS ON GROWTH PERFORMANCE OF *A. tortilis* AND *P. juliflora*....177
6.1 Introduction....178
6.2 Objectives....181
6.3 Materials and methods....181
6.3.1 Study site....181
6.3.2 Experimental design....182
6.3.3 Data analysis....184
6.4 Results....185
6.4.1 Effects of habitats and soil treatments on emergence of seedlings....185
6.4.2 Effects of habitats and soil treatments on survival of seedlings....180
6.4.3 Effects of habitats and soil treatments on seedling biomass....185
6.5 Discussion....189
6.5.1 Emergence of seedlings....189
6.5.2 Survival of seedlings....191
6.5.3 Biomass of seedlings....193
6.6 Conclusion....196
CHAPTER SEVEN: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS....197
7.1 General discussions....197
7.2 Conclusions....202
7.3 Recommendations....204
7.3.1 Further research....204
7.3.2 Conservation/Management actions....205
7.3.3 Policy intervention....206
References....207
APPENDICES....220
Appendix 1: Tree species in the study area, authors and families....220

Appendix 2a: Soil characteristics inside the floodplain..222
Appendix 2b: Soil characteristics outside the floodplain 223
Appendix 3a: Soil characteristics in wildlife conservation areas 224
Appendix 3b: Soil characteristics in livestock grazing areas...225
Appendix 3c: Soil characteristics in irrigated agricultural areas 226

LIST OF TABLES

Table 3.1: Comparison of mean densities (Mean±SE) of tree species found both inside and outside the floodplain......29

Table 3.2: Comparison of density means (Mean±SE) of shub species found both inside and outside the floodplain......32

Table 3.3: Comparison of Mean ±SE density of woody species saplings found both inside and outside the floodplain......35

Table 3.4: Comparison of the density of woody species seedlings found both inside and outside the floodplain (Mean±SE)......39

Table 3.5: Comparison of mean densities (Mean±SE) of forbs found both inside and outside the floodplain......41

Table 3.6: Comparison of density (Mean±SE) of perennial grass found both inside and outside the floodplain......42

Table 3.7: Comparison of basal areas (Mean±SE) of tree species found both inside and outside the floodplain......44

Table 3.8: Comparison of mean canopy cover (Mean±SE) of tree species found both inside and outside the floodplain.......46

Table 3.9: Comparison of IV 200 of tree species found both inside and outside the floodplain. 48

Table 3.10: ANOVA comparison of mean densities (Mean±SE) of tree species in more than one land use type......52

Table 3.11: ANOVA comparison of mean densities (Mean±SE) of shrub species in more than one land use type......55

Table 3.12: ANOVA comparison of mean densities (Mean±SE) of woody species saplings in more than one land use type......59

Table 3.13: ANOVA comparison of mean densities/m^2 (Mean±SE) of woody species seedlings in more than one land use type....62

Table 3.14: ANOVA comparison of mean densities (Mean±SE) of forbs in more than one land use type. 65

Table 3.15: ANOVA comparison of mean densities (Mean±SE) of perennial grasses in more than one land use type....67

Table 3.16: ANOVA comparison of basal area (Mean±SE) of tree species in more than one land use type 69

Table 3.17: ANOVA comparison of mean canopy cover (Mean±SE) of tree species in more than one land use type....72

Table 3.18: Comparison of IV 200 of tree species in more than one land use type.. ... .75

Table 4.1: Comparison of soil variables inside and outside the floodplain (Mean±SE) 101

Table 4.2: Comparison of soil variables across land use types (Mean±SE). 106

Table 4.3: Summary results of the first four CCA-axes of data from inside the floodplain..109

Table 4.4: Monte Carlo Permutation test results for significance of soil variables from inside the floodplain 109

Table 4.5: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species inside the floodplain....110

Table 4.6: Summary results of the first four CCA-axes of data from outside the floodplain. 113

Table 4.7: Monte Carlo Permutation test results for significance of soil variables from outside the floodplain. 114

Table 4.8: Correlation coefficients of soil properties with the ordination axes indicating their influence on the distribution of tree species outside the floodplain....115

Table 4.9: Summary results of the first four CCA-axes of data in conservation areas....117

Table 4.10: Monte Carlo Permutation test results for significance of soil variables from conservation areas. 118

Table 4.11: Correlation coefficients of soil properties with the ordination axes indicating their influence on the distribution of tree species in wildlife conservation areas. 118

Table 4.12: Summary results of the first four CCA-axes of data from livestock grazing areas. 121

Table 4.13: Monte Carlo Permutation test results for significance of soil variables from livestock grazing areas 122

Table 4.14: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species in livestock grazing areas. 123

Table 4.15: Summary results of the first four CCA-axes of data from irrigated agricultural areas.. 125

Table 4.16: Monte Carlo Permutation test results for significance of soil variables from irrigated agricultural areas 125

Table 4.17: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species in irrigated agricultural areas. 127

Table 5.1: Fisher's protected LSD test results for mean number of emerged seedlings in the location and subsample interactions. 146

Table 5.2: Fisher's protected LSD test results for mean number of emerged seedlings in the subsample and treatment interactions.. 147

Table 5.3: Fisher's protected LSD test results for mean survival of seedlings in the location and subsample interactions. 150

Table 5.4: Fisher's protected LSD test results for mean survival of seedlings in the treatment and location interactions.. 151

Table 5.5: Fisher’s protected LSD test results for mean survival of seedlings in the subsample and treatment interactions. 152

Table 5.6: Fisher’s protected LSD test results for mean shoot height of seedlings in the treatment and location interactions. 154

Table 5.7: Fisher’s protected LSD test results for mean shoot height of seedlings in the location and subsample interactions. 155

Table 5.8: Fisher’s protected LSD test results for mean taproot length of seedlings in the treatment and location interactions. 158

Table 5.9: Fisher’s protected LSD test results for mean taproot length of seedlings in the subsample and treatment interactions.. 159

Table 5.10: Fisher’s protected LSD test results for mean biomass of seedlings in the location and subsample interactions.. 162

Table 5.11: Fisher’s protected LSD test results for mean biomass of seedlings in the treatment and location interactions. 163

Table 5.12: Fisher’s protected LSD test results for mean biomass of seedlings in the subsample and treatment interactions.. 164

Table 6.1: Fisher’s protected LSD test results for the mean number of emerged seedlings in the treatment and species interactions...178

Table 6.2: Fisher’s protected LSD test results for the mean number of emerged seedlings in the habitat and species interactions...178

Table 6.3: Fisher’s protected LSD test results for mean seedling survival in the treatment and species interactions.. 181

Table 6.4: Fisher’s protected LSD test results for mean seedling survival in the species and habitat interactions. 184

Table 6.5: The mean seedling biomass in the four habitats. 186

Table 6.6: Fisher's protected LSD test results for mean seedling biomass in the treatment and species interactions. 187

LIST OF FIGURES

Figure 1.1: Conceptual framework 8

Figure 2.1: Map showing the location of the areas where samples were collected 15

Figure 3.1a: Cumulative number of tree species inside and outside the floodplain. 27

Figure 3.1b: Mean (±SE) densities of tree species found only inside the floodplain. 28

Figure 3.1c: Mean (±SE) densities of tree species found only outside the floodplain............ 28

Figure 3.2a: Cumulative number of shrub species inside and outside the floodplain. 30

Figure 3.2b: Mean (±SE) density of shrub species found only inside the floodplain..............31

Figure 3.2c: Mean (±SE) density of shrub species found only outside the floodplain......... ..31

Figure 3.3a: Cumulative number of woody species saplings inside and outside the floodplain. 32

Figure 3.3b: Mean (±SE) densities of woody species saplings found only inside the floodplain.. 34

Figure 3.3c: Mean (±SE) densities and standard errors of woody species saplings found only outside the floodplain...35

Figure 3.4a: Cumulative number of woody species seedlings inside and outside the floodplain. 36

Figure 3.4b: Mean densities and standard errors of woody species seedlings found only inside the floodplain....... 37

Figure 3.4c: Mean densities and standard errors of woody species seedlings found only outside the floodplain...38

Figure 3.5a: Cumulative number of forb species found inside and outside the floodplain. 39

Figure 3.5b: Mean densities and standard errors (Mean±SE) of forbs found only inside the floodplain.. 40

Figure 3.5c: Mean densities and standard errors (Mean±SE) of forbs found only outside the floodplain..40

Figure 3.6: Cumulative number of perennial grass species inside and outside the floodplain. 41

Figure 3.7a: Mean basal area and standard errors (Mean±SE) of tree species found only inside the floodplain...43

Figure 3.7b: Mean basal area and standard errors (Mean±SE) of tree species found only outside the floodplain..43

Figure 3.8a: Mean canopy cover and standard errors (Mean±SE) of tree species found inside the floodplain. 45

Figure 3.8b: Mean canopy cover and standard errors (Mean±SE) of tree species found outside the floodplain.. 46

Figure 3.9a: IV 200 of tree species inside the floodplain. 47

Figure 3.9b: IV 200 of tree species outside the floodplain. 48

Figure 3.10a: Cumulative number of tree species per land use. 49

Figure 3.10b: Mean densities (Mean± SE) of tree species found only in wildlife conservation areas. 50

Figure 3.10c: Mean densities (Mean± SE) of tree species found only in livestock grazing areas. 50

Figure 3.10d: Mean densities (Mean±SE) of tree species found only in irrigated agricultural areas. 51

Figure 3.11a: Cumulative number of shrub species per land use. 52

Figure 3.11b: Mean densities and standard errors (Mean±SE) of shrub species found only in conservation areas...53

Figure 3.11c: Mean densities and standard errors (Mean±SE) of shrub species found only in livestock grazing areas. 54

Figure 3.12a: Cumulative number of woody species saplings per land use. 55

Figure 3.12b: Mean densities and standard errors of woody species saplings found only in conservation areas.. 57

Figure 3.12c: Mean densities of woody species saplings found only in livestock grazing areas. 58

Figure 3.12d: Mean densities of woody species saplings in irrigated agricultural areas. 58

Figure 3.13a: Cumulative number of woody species seedlings per land use. 60

Figure 3.13b: Mean densities and standard errors of woody species seedlings found only in wildlife conservation areas.. 61

Figure 3.13c: Mean densities and standard errors of woody species seedlings found only in livestock grazing areas.. 61

Figure 3.14a: Cumulative number of forb species per land use. 63

Figure 3.14b: Mean densities and standard errors of forb species found only in wildlife conservation areas. 64

Figure 3.14c: Mean densities and standard errors of forb species found only in livestock grazing areas 64

Figure 3.14d: Mean densities and standard errors of forb species found only in irrigated agricultural areas 65

Figure 3.15: Cumulative number of perennial grass species per land use. 66

Figure 3.16a: Mean basal areas and standard errors of tree species found only in wildlife conservation areas. 68

Figure 3.16b: Mean basal areas and standard errors of tree species found only in livestock grazing areas 68

Figure 3.16c: Mean basal areas of tree species found only in irrigated agricultural areas. 69

Figure 3.17a: Mean canopy cover and standard error of tree species found only in wildlife conservation areas. 70

Figure 3.17b: Mean canopy cover and standard errors of tree species found only in livestock grazing areas. 71

Figure 3.17c: Mean canopy cover and standard errors of tree species found only in irrigated agricultural areas.... 71

Figure 3.18a: IV 200 of tree species found only in wildlife conservation areas. 74

Figure 3.18b: IV 200 of tree species found only in livestock grazing areas. 74

Figure 3.18c: IV 200 of tree species found only in irrigated agricultural areas. 75

Figure 4.1: CCA biplot showing the influence of soil variables on tree species distribution patterns inside the floodplain 112

Figure 4.2: CCA biplot showing the influence of soil variables on tree species distribution patterns outside the floodplain 116

Figure 4.3**:** CCA biplot showing the influence of soil characteristics on tree species distribution patterns in wildlife conservation areas.... 120

Figure 4.4: CCA biplot showing the influence of soil characteristics on tree species distribution patterns in livestock grazing areas. 124

Figure 4.5: CCA biplot showing the influence of soil characteristics on tree species distribution patterns in irrigated agricultural areas 128

Figure 5.1: Mean number and standard errors of emerged seedlings per treatment inside and outside the floodplain. 145

Figure 5.2: Mean survival and standard errors of subsample seedlings per treatment inside and outside the floodplain. 149

Figure 5.3: Mean shoot height (cm) and standard errors of subsample seedlings per treatment inside and outside the floodplain 153

Figure 5.4: Mean taproot length (cm) and standard errors of subsample seedlings per treatment inside and outside the floodplain 157

Figure 5.5: Mean biomass (g) and standard errors of subsample seedlings per treatment inside and outside the floodplain..161

Figure 6.1: A mature *Prosopis juliflora* (Sw.) DC. tree 183

Figure 6.2: A mature *Acacia tortilis* (Forssk.) Hayne tree 183

Figure 6.3: The mean number and standard errors of emerged *Acacia tortilis* and *Prosopis juliflora* seedlings per habitat for the different soil treatments...185

Figure 6.4: The mean number and standard errors of all emerged seedlings per habitat in soil with different treatments...180

Figure 6.5: Mean survival and standard errors per habitat in each soil treatment for *Acacia tortilis* and *Prosopis juliflora* seedlings...181

Figure 6.6: Mean survival and standard errors of all seedlings per habitat in soil with different treatments...185

Figure 6.7: Mean biomass and standard errors per habitat in each soil treatment for *Acacia tortilis* and *Prosopis juliflora* seedlings...186

Figure 6.8: Mean biomass and standard errors of all seedlings per habitat in the different soil treatments...188

ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of Variance

CCA: Canonical Correspondence Analysis

CEC: Cation Exchange Capacity

DBH: Diameter at Breast Height

ENSO: El Nino-Southern Oscillation

IPCC: Intergovernmental Panel on Climate Change

IUCN: International Union of Conservation of Nature

IV: Importance Value

KWS: Kenya Wildlife Service

LSD: Least Significant Difference

NEMA: National Environment Management Programme

RoK: Republic of Kenya

UNEP : United Nation Environment Programme

ABSTRACT

Floodplains of rivers in semi-arid areas of Africa are important areas for agriculture, livestock grazing and wildlife conservation. However, floods and anthropogenic disturbances affect soil properties, which subsequently influence natural plant community structure, and create favourable conditions for invasive species to establish. The dynamics of tropical African floodplain vegetation in relation to flooding regime, soil characteristics and farming activities has not been widely investigated and hence is not well understood. The purpose of this study was to investigate how floodplain vegetation responds to changes in flood regime, soil characteristics and different levels of human disturbance. The objectives were to (1) determine the variation in vegetation structure of plant species with the cross-sectional floodplain gradient and across the main land use types; (2) determine the influence of soil properties on the distribution of tree species; (3) determine the effects of herbaceous defoliation and cultivation on emergence, survival and growth of *Acacia tortilis* (Forssk.) Hayne and *Prosopis juliflora* (Sw.) DC. seedlings on and off the floodplain and (4) determine the effects of site characteristics and soil treatments on emergence, survival and biomass of *Acacia tortilis* and *Prosopis juliflora* seedlings. Vegetation and soil data were collected along transects running perpendicular to the river towards the land in the upper Tana River floodplain. The transects cut across different vegetation types and land uses, namely; wildlife conservation, livestock grazing and irrigated agriculture. An experiment was set up to determine the effect of defoliation and cultivation on emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* seedlings on and off the floodplain. Another experiment was set up to determine the effects of site characteristics and different soil treatments on emergence, survival and biomass of the two species. The mean densities of the woody and non-woody species, the basal areas and canopy covers of the tree species and soil properties were compared using a t-test for between vegetation found inside and outside the floodplain. Analysis of variance (ANOVA) was used to compare the vegetation and soil data based on various land use types. Canonical Correspondence Analysis (CCA) was used to relate the soil properties to the distribution of tree species using Importance Value (IV 200) as the measure of abundance. The experimental data were subjected to a three-way ANOVA and the group means compared using Fisher's Protected Least Significant Difference, both at 5% significant level. For further analysis, the vegetation data were separated into three groups: species occurring in the floodplain only, those that occurred outside the floodplain only and those that occurred both inside and outside flood plain. The mean basal area ($t_{(349)} = -4.54$, $P < 0.001$) and the canopy cover ($t_{(349)} = -3.87$, $P < 0.\ 01$) of trees were significantly higher outside than inside the floodplain. The densities of the forbs ($t_{(106)} = 4.44$, $P < 0.01$) and the perennial grasses ($t_{(58)} = 2.33$, $P = 0.02$) were significantly higher inside the floodplain. The invader *Prosopis juliflora* had also significantly higher mean density ($t = 5.44$, $P < 0.01$) and lower mean basal area ($t = -2.24$, $P = 0.03$) inside than outside the floodplain. *Prosopis juliflora* contributed 33.2 and *Acacia tortilis* (19.65) to IV 200. These were also the highest importance values inside and outside the floodplain respectively. The basal area of *Prosopis juliflora* was significantly higher in wildlife conservation areas ($F = 2.61$, $P = 0.04$) than in any other land use type. Its seedling density was also significantly higher in irrigated agricultural areas ($F = 3.13$, $P = 0.05$) than in any other land use type. Irrigated agricultural areas contributed the least to IV 200. Moisture ($t = 5.92$), pH ($t = 2.03$), P ($t = 5.91$), Mg ($t = 3.25$) and Ca ($t = 2.04$) were significantly higher inside the floodplain ($P < 0.05$), and bulk density outside the floodplain ($t = -8.76$, $P < 0.05$). Soil properties influenced the distribution of trees in the study area. The emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* species were significantly higher inside the floodplain ($P < 0.01$). Seedlings emergence, survival and growth were significantly high in heavily defoliated and cultivated plots, on bare soil and in cow dung ($P < 0.05$). Seedlings of *Prosopis juliflora* and *Acacia tortilis* did not survive in perennial grass on the soil surface while the latter did not survive under *Prosopis juliflora* canopy. In the different environmental conditions, *Prosopis juliflora* was more successful than *Acacia tortilis*. In conclusion, the results show that changes in flooding regime of River Tana due to impoundments upstream compounded by the impacts of climate variability, changes in soil properties due to reduced silt loading and anthropogenic disturbances can modify the flood plain ecosystem. These affect the plant species dynamics and create favourable conditions for establishment of invasive plant species. The outcomes have serious negative implications on the value of the floodplain wetlands as prime areas for agriculture, livestock grazing and wildlife conservation. Human activities , which appear to facilitate proliferation of invasive woody species in the fragile floodplain ecosystem, should be regulated to conserve indigenous plant communities and control invasion.

Key words: Plant composition, soil properties, anthropogenic disturbances, invasive *Prosopis juliflora*, *Acacia tortilis*, seedling emergence, biomass and survival; Tana River Flood plain.

PUBLISHED ARTICLES FROM THIS RESEARCH WORK

1. Omari J. K., J. K. Mworia, N. Gichuki and C. Mligo (2019). Woody Species Composition in Upper Tana River Floodplain of Kenya: Potential Effects of Change in Flood Regimes. *Journal of sustainability, environment and peace* 1(3): 91–97

2. Omari J. K., J. K. Mworia, N. Gichuki and C. Mligo (2020). The influence of soil properties on the distribution pattern of tree species on and off the floodplain in the Tana River area of Kenya. *Journal of sustainability, environment and peace* 3(1): 1- 7

CHAPTER ONE: INTRODUCTION

1.1 Characteristics of Savanna ecosystems

Savanna ecosystems are important as they support and provide food for humanity, domestic livestock as well as wild animals. In these ecosystems, trees co-exist with the herbaceous layer which consists mainly of grasses (Scholes & Archer, 1997; Jeltsch *et al.* 2000; House *et al.* 2003). The Competition and the demographic-bottleneck models have been used to explain the co-existence of trees and grasses based on the variables that structure plant community (Sankaran *et al.* 2004). These variables include fire regimes, rainfall and grazing by herbivores (Frost *et al*. 1986; Archer, 1995), competition for resources (Scholes & Archer, 1997; Ehrenfeld, 2003), climate influence (Lovejoy & Hannah, 2006), introduced invasive plant species (Levine *et al*. 2003; Brooks *et al*. 2004) and disturbances caused by floods (Amoros & Bornette, 2002; Child *et al.* 2010).

The difference in acquisition of resources between trees and grasses help to structure the savanna communities in the competition-based models (Fernandez-Illescas & Rodriguez-Iturbe, 2003; Van Langevelde *et al*. 2003). Although moisture and nutrients are both necessary for plant growth, competition for the former resource limits the growth of trees and grasses in savanna ecosystems (Sankaran *et al.* 2004). In demographic-bottleneck models, climatic variability and/or disturbances like fires and grazing are the bottlenecks that enable trees and grasses to coexist. The bottlenecks are the limiting factors that prevent satisfactory germination of tree seeds, establishment, growth and survival to adulthood (Higgins *et al*. 2000; Van Wijk & Rodriguez-Iturbe, 2002). These models also consider the role of interactions between disturbances and life-history dynamics in structuring savanna plant communities (Sankaran *et al.* 2004). However, rather than separately using the two models to explain the existence of trees and grasses in savanna ecosystems, competitive effects should be incorporated into demographic-bottleneck models to give a more reliable model (Sankaran *et al*. 2004).

A number of factors threaten the existence of woody plant species and upset the tree-grass balance in savanna ecosystems in arid and semi-arid regions. These factors include unsustainable methods of utilizing environmental resources (Abdelfattah, 2009) such as harvesting plants and their products for food, medicine, fuel wood, production of charcoal as well as building poles and timber (Dovie *et al.* 2002; Kristensen & Lykke, 2003). As human population continues to increase, these threats increase proportionally and affect vegetation abundance, diversity and distribution. The increased human population in Tana River has led to unsustainable land use practices that include intense livestock grazing and cultivation. Some areas are highly invaded by *Prosopis species* which were introduced in this semi-arid region in the 1980s (Choge *et al*. 2002). These plants have become invasive and threaten the performance of indigenous plant species because they are more competitive for resources and can thus displace key indigenous species. In addition, the existing climate variability will likely lead to extreme variations in soil nutrients & moisture, increased competition between invasive and indigenous species and increased intensity of disturbances such as grazing. The vegetation dynamics in Tana River have not been studied in the light of these changes, hence the importance of this study.

1.2 Drivers of plant community dynamics

1.2.1 Climate variability

The increased concentration of greenhouse gases caused by burning of fossil fuel, farming, and other anthropogenic ventures contributes significantly to climate variability (Lovejoy & Hannah, 2006). Changes in global heat balance have implications on the hydrological cycle reflected by increase in the frequency of heavy rainfall events in terrestrial precipitation (Lovejoy & Hannah, 2006). In addition, the El Nino-Southern Oscillation (ENSO) is a major driver of the interannual variability in eastern African rainfall, with a significant impact on vegetation (Fer *et al*. 2017).

Climate change is thought to trigger range shifts and changes in abundance of plant species. Observed trends indicate that species with naturally low dispersal capacity are less responsive to regional warming than species with naturally high dispersal capacity. Vegetation shifts have also been related to changes in precipitation. However, empirical evidence suggests that it is climate variability – extreme climate years (e.g. droughts and ENSO events) that influence species dynamics more than change in yearly mean climatic conditions. Extreme weather and climate events appear to be increasing in magnitude and frequency; hence, more range shifts in wild species are expected in future (Lovejoy and Hannah, 2006). This is particularly relevant to savanna region of East Africa, where the frequency of droughts is predicted to increase well above the long-term average (Adger *et al*. 2003).

1.2.2 Bush Encroachment

Encroachment of woody plant species into rangelands has been related to climatic change, increased grazing intensity by livestock, reduction in fire frequency, and interactions among these factors (Polley *et al*. 2002). Encroachment causes an imbalance in vegetation structure due to alteration of the tree-grass ratio, which reduces the production of desirable grasses and thus affects both wildlife and livestock (Archer & Smeins, 1991). However, plant community composition may also be modified in semi-arid grasslands due to variation in precipitation, fire and grazing regimes (Archer, 1994).

1.2.3 Livestock

Plant community structure and processes that drive ecosystems can be influenced by livestock grazing either directly or indirectly. Changes in microenvironment, soil physical and chemical properties, plant competitive interactions, and fire regimes are indirect effects of livestock grazing (Archer, 1995). The direct effects are related to changes in plant physiology and morphology caused by defoliation and trampling by grazing animals, which increase compaction of the soil surface (Archer, 1995).

The effects of increased soil compaction may favour recruitment of some woody species over grasses (Braunack & Walker, 1985). On the other hand, increased soil compaction may prevent recruitment of some woody species such as *Prosopis caldenia* (Distel *et al.* 1996). Soils with a high bulk density limit water infiltration, which affects successful germination of many woody plant seedlings. This is because the seeds of many woody species germinate during periods when competition for soil water is minimal (Schwinning & Ehleringer, 2001). As domestic herbivores consume the pods of plants such as *Prosopis juliflora* and *Acacia tortilis,* they act as effective dispersal agents and thus also regulate plant community dynamics. They do so by facilitating sclarification of the seeds as they pass through their digestive system (Peinnetti *et al.* 1993), breaking their dormancy. In addition, deposition of dung makes a favourable environment to support germination and growth of plant species seedlings (Cypher & Cypher, 1998).

1.2.4 Non-indigenous Invasive Species

One of the key environmental problem confronting natural resource managers in African savannas is invasion by non-indigenous plant species (Foxcroft & Richardson, 2003; Henderson, 2007). These species can modify community structure, functioning and diversity of savanna ecosystems by altering the impacts caused by fire (Brooks *et al*. 2004) and cycling of nutrients (Ehrenfeld, 2003), leading to loss of indigenous biodiversity (Levine *et al*. 2003). These researchers have therefore suggested that the spread of invasive plant species in African savannas can be controlled by manipulating the availability of resources and reducing disturbances so as to enhance indigenous biodiversity conservation.

Prosopis juliflora, native to Central America, was introduced in some arid and semi-arid areas of Kenya in the 1980's through rehabilitation, afforestation and fodder production projects (Mwangi & Swallow, 2005). The plant was considered suitable because of its high tolerance to drought compared to the indigenous species (Olukoye *et al. 2003).* In Kenya, the National Environment Management Authority (NEMA, 2004), reported that the plant had spread rapidly in semi-arid areas, causing changes in the structure of native plant communities.

According to Maundu *et al.* (2009), about 50% of Kenya's surface area has a probability of 30% or more of *Prosopis* invasion, with arid lands facing the greatest risk of colonization. The negative impacts of *Prosopis* species on local plant and animal communities are causing concern among the affected communities of farmers and pastoralists in Kenya (Mwangi & Swallow, 2005; Maundu *et al.* 2009). The protected areas in Kenya have not been spared from invasion, leading to decline in biodiversity (Maundu *et al.* 2009).

Invasive plants are more competitive for water and plant nutrients and hence tend to displace indigenous plant species. As *Prosopis* species tap into underground water sources in dry river beds, riparian zones and lowlands, the roots block watercourses and exacerbate the effects of flooding (Mwangi & Swallow, 2005). This can affect the sustenance of the communities living in the dry regions where climate variability causes frequent floods and extended droughts. Clearing one hactare of invasive *Prosopis* species from the riparian zone of the Rugseer River in South Africa reduced groundwater use by 50 m^3 month (Fourie *et al.* 2003). The high utilization of water by *Prosopis* species would reduce the available water in floodplains, interfering with the source of livelihood for the local communities. This is because floodplains in dry areas are important agricultural zones and grazing refuges during the periods of climatic drought.

1.2.5 Seasonal river flooding

In areas affected by floods and sedimentation, seasonal river flooding can act as a natural disturbance, structuring wetland and aquatic communities (Amoros & Bornette 2002). Flooding can cause abrupt change in natural plant communities (Resh *et al.* 1988), and is responsible for structuring the spatial heterogeneity in river floodplains (Ward *et al*. 2006). Flood events in a neotropical floodplain of upper Parana River was found to disrupt community organisation of macrophyte assemblages at local scales (Padiel *et al.* 2009).

Climate change, (signalled by extreme floods and droughts) is likely to increase economic, social and environmental costs (UNEP, 2000; Mogaka *et al.* 2006; Speranza *et al*. 2008). In the Republic of Kenya, floods have become the most frequent climatic catastrophe (RoK, 2007), with riverine ecosystems being the most affected (Otiende, 2009). According to the intergovernmental panel on climate change, the risks of floods will significantly increase in the developing world with increased climate variability at elevated temperatures (IPCC, 2007). In the long run, flooding will contribute an important role in the maintenance of the function and biological diversity of riverine ecosystems (Poff *et al*. 1997). The occurrence of Flood disturbance has been reported to alter tree-grass ratio in a semi-arid savanna system in South Africa (Child *et al.* 2010).

1.3 Conceptual framework

Environmental conditions, plant community dynamics and human activities are interdependent and hence affect each other as illustrated in the conceptual framework of this study (Figure 1.1). Environmental conditions determine the performance of plants and hence affect community structure. The floodplain experiences flooding which deposits sediments unlike the areas outside the floodplain. This increases soil nutrients and moisture level in the floodplain, which promote vegetation regeneration and growth. On the other hand, fluctuations in river flow and flooding due to climate variability and dam construction alters the hydrology in the floodplain, which can shift the composition of vegetation dynamics. Soil properties support regeneration and survival of plants, upon which human communities depend on for survival. In Tana River County, plants are harvested to provide fibre, poles and timber for construction, charcoal production and firewood, which affects plant community structure dynamics. Crop farming and livestock grazing, which are the main anthropogenic activities, require suitable environmental conditions to continue supporting the increasing human population. Among the important ecological factors are soil properties which should be protected for ecological sustainability despite the natural and anthropogenic disturbances.

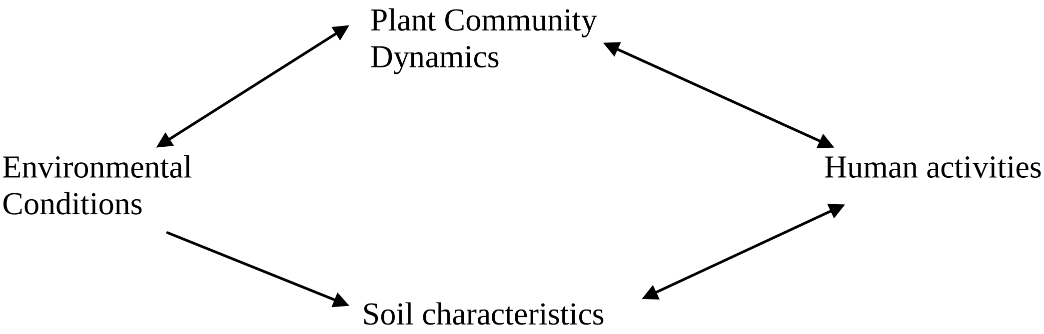

Figure 1. 1: Conceptual framework

The predictions of the study were:

- There would be differences in plant community structure inside and outside the floodplain and in the different land use types
- There would be variations in soil properties inside and outside the floodplain and across the different land use types
- Soil properties influenced the distribution of tree species
- Human activities affected plant regeneration and life-history dynamics
- Site characteristics and soil treatments would affect plant regeneration and life-history dynamics

1.4 Justification

According to Muturi *et al.* (2009), *Prosopis* is rapidly displacing *Acacia tortilis* in riverine ecosystems in Kenya. Furthermore, Mworia *et al.* 2011 observed higher establishment of *Prosopis juliflora* inside than outside the floodplain in the upper Tana River region. The increased density of *Prosopis juliflora* in the floodplain caused a significant decline in the diversity of the indigenous woody species. The variation in the density of this invasive plant and that of indigenous species has not been compared along the cross-sectional floodplain gradient and among the land use practices in the upper Tana River region.

The critical and often the most limiting stage in tree life-history is the seedling establishment stage (Sankaran *et al.* 2004). This is especially so in arid and semi-arid regions, where natural precipitation is the only source of moisture, which is critically important for germination, establishment and growth of woody plant species. It is therefore important to compare invasive and indigenous plants in their early stages of development in the light of climate variability and land use changes. In this case, comparison between *Prosopis juliflora* and *Acacia tortilis* in terms of seedling emergence, survival and growth.

Climate change in East African drylands is predicted to be characterized by increased frequency of droughts and flood events. Such events in floodplains lead to extreme variations in soil nutrients and moisture, increased competition with non-indigenous species and intensity of disturbances due to grazing. In addition, flood control through construction of dams, coupled with climate variability, influence flooding regimes which affect vegetation dynamics in floodplains found in drylands. The effects of these on vegetation dynamics have not been studied in upper Tana River floodplain.

The findings of this research will show the response of vegetation to changes in flood regime, soil characteristics and human disturbances. Regulation of human activities is necessary to enhance conservation of plant communities and control invasion. Development of appropriate mitigation and adaptation strategies to counteract the effects of climate variability on vegetation composition and structure in African river floodplains in arid and semi-arid savannas is important. This can assist in identification of effective management strategies in the light of increasing human population.

1.5 Research Questions

1) How does the population structure of plant species vary with the cross-sectional floodplain gradient and with land use types?

2) How do soil properties influence the distribution of tree species?

3) How does herbaceous defoliation and cultivation affect the emergence, survival and growth of *P. juliflora* and *A. tortilis* seedlings inside and outside the floodplain?

4) What are the effects of site characteristics and different soil treatments on emergence, survival and biomass of *P. juliflora* and *A. tortilis* seedlings*?*

1.6 Main objectives

The aim of this research was to determine the response of vegetation to changes in flood regime, soil characteristics and human disturbances. The objectives were;

1) To determine the variation in population structure of plant species with cross-sectional floodplain gradient and across the main land use types.

2) To determine the influence of soil properties on the distribution of tree species in the study area.

3) To determine the effects of herbaceous defoliation and cultivation on emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* seedlings on and off the floodplain.

4) To determine the effects of site characteristics and different soil treatments on emergence, survival and biomass of *Prosopis juliflora* and *Acacia tortilis* seedlings.

1.7 Thesis structure

The structure of this thesis is outlined below as presented in the different chapters;

Chapter 2: Materials and methods

Chapter 3: Composition, abundance and richness of vegetation

Chapter 4: Tree species distribution in relation to soil properties inside and outside the floodplain and among land use types

Chapter 5: Effects of herbaceous defoliation and cultivation on emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* seedlings on and off the floodplain

Chapter 6: Effects of site characteristics and soil treatments on emergence, survival and biomass of *Prosopis juliflora* and *Acacia tortilis* seedlings

Chapter 7: General discussions, conclusions and recommendations

CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS

2.1 The Study Area

The study area is located in South-eastern Kenya in Tana River County, where Tana River, the longest river in Kenya and after which the county is named, passes through. The river is approximately 1000 kilometres long, and it flows from Mt. Kenya and the Aberdare Mountains to the Indian Ocean (Maingi, 2006). It experiences floods twice annually, with peaks in May and in November in response to the long and short rainy seasons that occur in the river catchment area located in Mount Kenya and the Aberdare Range (Maingi, 2006). The low flows are longer and more severe in August–October compared to the February–March period (Maingi & Marsh, 2002). The river is a life support system for the people in this area as the water is used for irrigation of crops and fodder, watering of livestock and for domestic use. The floodplain is an asset because it contains more moisture and nutrients compared to the area outside the terrestrial environments. The stretch of the floodplain is about 200km long and extends from Garissa which is the upstream side to the downstream at Garsen, where the delta begins.

The rainfall in the basin is lowest at Garissa which receives 300mm/year, and increases to 600mm/year at Garsen (Hughes, 1990). The rainfall is bimodal and highly variable with the long rainy season in March–May, and the short rainy season in October–November, with slightly more rainfall falling in the short rainy season (Maingi, 2006). Mean annual temperature is 28.0ºC with February and July the hottest, and coldest, months respectively. According to Maingi & Marsh, 2002, construction of hydropower dams in the upper catchment has resulted in a decrease in the peak flow in May and an increase from December to March. This has affected the meandering dynamics and resulted to reduced flooded surface area and flood peak duration, negatively affecting forest regeneration and floodplain productivity. The government of Kenya has undertaken to construct a new mega dam to support irrigation based farming in the light of food shortage, and address the problems caused by floods. The new dam will, however, further alter flood regimes with disastrous effects on crop farming and the vegetation downstream.

The key vegetation types include gallery forests, *Acacia* woodlands, and *Acacia-Commiphora* scrub vegetation interspersed by seasonal grasslands (Hughes, 1990). Some trees are found along the lagas (seasonal streams) and form some patches composed of *Acacia tortilis* (Forssk.) Hayne, *Acacia senegal* (L.) Willd., *Berchemia discolour* (Klotzsch) Hemsl., *Hyphaene compressa* H.Wendl., *Salvadora persica* L. and *Dobera glabra* (Forssk.) Poir (Gachathi *et al.* 1987). The globally renowned invasive *Prosopis* species have become a major concern to conservationists as well as the local communities in this region. A report by the Kenya Forest Research Institute and Forestry Department indicated large-scale invasions in Tana River County (Choge *et al*. 2002). Mworia *et al.* (2011) also found the density of *Prosopis juliflora* to be high in the upper Tana River floodplain. Moreover, observation during reconnaissance study indicated that the density of *Prosopis* species was relatively high within the floodplain and in the irrigation schemes.

The land use practices in the study area are irrigated agriculture, wildlife conservation and livestock grazing. Irrigated agriculture is practiced in Bura and Hola Irrigation schemes which are located outside the floodplain. These schemes have suffered massive invasion by *Prosopis* species and as a result had largely been abandoned by 2002. The Pokomo people practice irrigated agriculture (shifting cultivation) in sections of the river bank (KWS, 1996). They depend on both floodwater to irrigate their crops, and on the depositions of fertile sediments brought by the floods (IUCN, 2003). In the absence of floods, some farmers pump water directly from the river to irrigate their crops. Farming in the floodplain is therefore largely dictated by the availability of floods, which determine establishment of farms and their permanence based on soil fertility.

There are two wildlife conservation units in the study area that serve to conserve biodiversity. These are Arawale National Reserve, which is open to livestock grazing and Tana River National Reserve, which is not open to livestock grazing. Arawale National Reserve started in 1973 to protect the endangered and endemic hirola antelope (*Beatragus hunteri*, Sclater 1889) (Dahiye & Aman, 2002; IUCN, 1996). The Tana River National Primate Reserve was established in 1976 to protect the forests that are home for two endangered primates namely: the Tana River Red Colobus (*Procolobus rufomitratus* Peters), and the Tana River Crested Mangabey (*Cercocebus galeritus* Peters), which are both endemic to the area (IUCN 1996, Muoria *et al.* 2003). Five other primate species have also been identified within this reserve (Suleman *et al.* 2001).

Livestock grazing (pastoralism) is practiced in the dry semi-arid areas outside the floodplain by nomadic tribes (the Orma, Somali and Wardei), while agrarian communities, especially the Pokomo people, keep small numbers of livestock (Mworia *et al*. 2011). During the dry season, pastoralists take their livestock to graze within the floodplain which has more pasture. Occasionally, the livestock destroy crops as they graze or partake of the common resource, water. This often occurs during periods of extended drought and leads to a serious conflict between the crop and the livestock owners over damages to crops.

The ecosystem is deemed to be under severe threat due to changes in the flooding regime and drought frequencies brought about by climate variability, and increasing invasion by *Prosopis* species. Changing land use practices such as grazing intensity and cultivation to support the increasing human population have also added pressure on the ecosystem. Thus, a field survey was conducted in the upper Tana River in order to determine the extent of the above threats on vegetation structure, composition and distribution. Data were collected inside and outside the floodplain based on the main land use practices namely irrigated agriculture, livestock grazing and wildlife conservation. The areas considered suitable for data collection were Tana River National Reserve, Arawale National Reserve, Bura Irrigation Scheme, Hola Irrigation Scheme, Bura, Bura East, Hola, Makere, Chanani and Wenje (Figure 2.1).

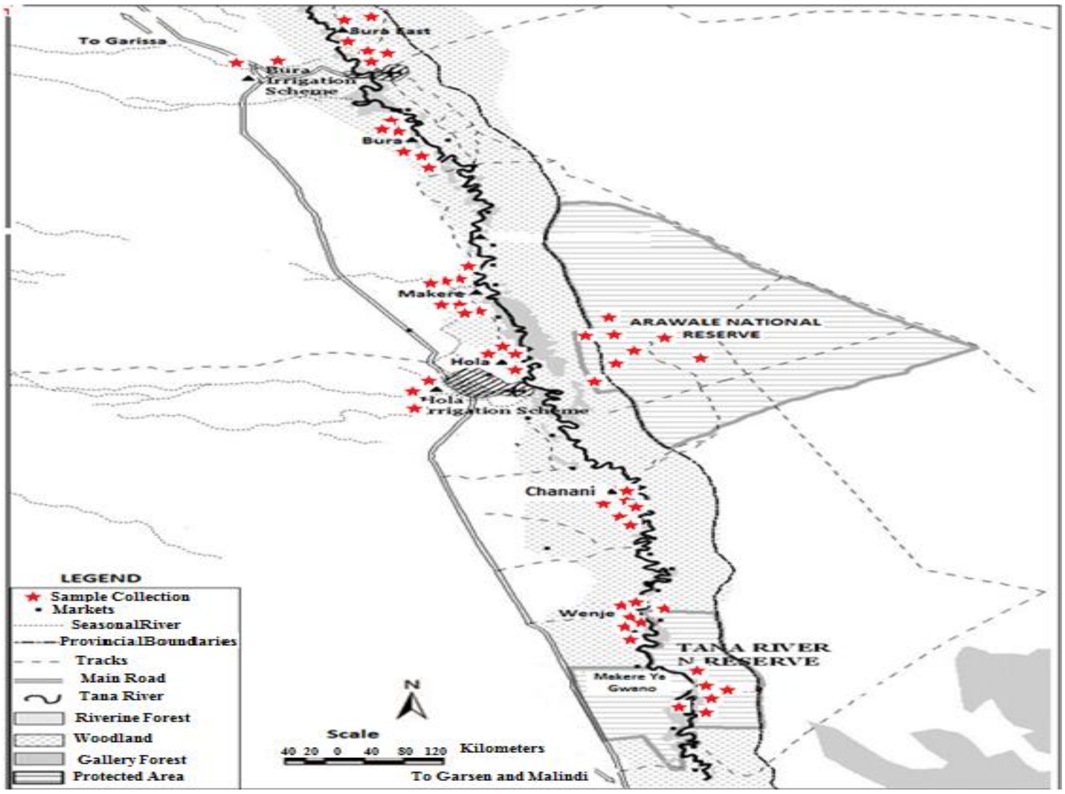

Figure 2. 1: Map showing the location of the areas where samples were collected (source: Omari *et al.* 2019)

2.2 Research Plan

The study consisted of a field survey and two sets of field experiments to address the objectives. The field survey involved collecting vegetation data in order to determine the variation in population structure of *Prosopis juliflora, Acacia tortilis,* and other plant species in relation to cross-sectional floodplain gradient and the main land use practices. Soil samples were collected alongside the vegetation data and analyzed to determine their effect on the distribution of *Prosopis juliflora, Acacia tortilis* and other tree species in the study area.

The first field experiment monitored the effects of herbaceous defoliation and cultivation on the emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* seedlings inside and outside the floodplain. The second field experiment monitored the effects of site characteristics and soil treatments on emergence, survival and biomass of *Acacia tortilis* and *Prosopis juliflora* seedlings. The findings of this research will provide crucial information for management purposes in the light of changing climate and land use practices due to the increasing human population pressure as well as increasing invasion by *Prosopis juliflora.*

2.3 Sampling procedure

2.3.1 Vegetation sampling

The data were collected in the study area using transect method that combined with the plot method. Vegetation data were collected using 10m x 10m plots for trees, 5m x 5m subplots nested in the 10m x 10m plots for shrubs and saplings, and 0.5m x 0.5m quadrats placed randomly within the 5m x 5m subplots for seedlings and non-woody plants. The plots were laid along 100m line transects which ran perpendicular to the river. All the woody species (trees and shrubs), saplings, seedlings, forbs, perennial grasses in the respective quadrats were identified and counted. The details of vegetation data sampling are outlined in chapter 3.

2.3.2 Sampling and laboratory analysis of soil samples

Soil samples were collected alongside the vegetation data within the 0.5m x 0.5m quadrats using core rings and a soil augur. The soil samples extracted using the core rings were weighed in the field and put in a coolant for analysis of soil moisture and bulk density. In the laboratory, the soils in the core rings were re-weighed before being oven-dried. The dry soil samples were then weighed in order to determine the bulk density and the moisture content using the gravimetric method. The soil samples collected using a soil augur was analyzed for the other variables. The detailed methods are outlined in chapter 4.

2.4 Experiment 1: Effects of herbaceous defoliation and cultivation on emergence, survival and growth of *A. tortilis* and *P. Juliflora* seedlings on and off the floodplain

Acacia tortilis is an important indigenous tree species in the study area whereas *Prosopis juliflora,* a key invader that is suspected to be displacing it. The above experiment was designed to determine the effect of the floodplain, grazing intensity and cultivation on the emergence, survival and growth of the two species. Two sites were selected and fenced, one inside the floodplain, another outside the floodplain. Within the enclosures, 1m x 1m plots were measured and different levels of herbaceous vegetation defoliation were used to simulate a range of grazing intensities before planting the seeds at the beginning of the rainy season in March. The details of the experimental design are outlined in chapter 5.

2.5 Experiment 2: Effects of site characteristics and soil treatments on the emergence, survival and biomass of *Acacia tortilis* and *Prosopis Juliflora* seedlings

The above experiment was carried out during the rainy season for 3 months in four different habitat types; under mature *Acacia tortilis* canopy, under mature *Prosopis juliflora* canopy, in the perennial grass (*Tetrapogon bidentatus*) and on bare soil. Three treatments were applied to the seeds of both plant species in each habitat to simulate scattered loose seeds on the soil, seeds under cow dung and seeds in soil. The details of the experimental design are outlined in chapter 6.

2.6 Data Analysis

2.6.1 Analysis of vegetation data

The vegetation data were analyzed based on the cross-sectional floodplain gradient and the main land use practices in the study area. The densities were determined per square hectare for the woody plant species and per square meter for the non-woody plant species. Genstat Software, 15th Edition (Payne, *et al*. 2012), was used to assess the differences in the density of vegetation, canopy cover and basal area of trees using Student t-test and analysis of variance (ANOVA).

2.6.2 Analysis of soil data

Soil variation inside and outside the floodplain was assessed using Student t-test, and between different land use practices using analysis of variance (ANOVA). Canonical correspondence analysis (CCA) was used to determine the variation in habitat preference (distribution) of tree species as influenced by the soil characteristics namely bulk density, moisture, pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations (K, Na, Ca, Mg) and cation exchange capacity (CEC).

2.6.3 Analysis of experimental data

Data for field experiment 1 was analyzed using three - way ANOVA for emergence, survival and growth of seedlings; the three factors being floodplain (inside and outside), defoliation level and species. Thus, the number of seedlings that emerged and those that survived, the shoot height, taproot length, and the biomass data were subjected to a three-way ANOVA that included floodplain, defoliation level and species. In field experiment 2, the number of seedlings that emerged, survived and the biomass of the surviving seedlings were also subjected to three-way analysis of variance that included species, soil treatment and habitat.

The details of analysis for the field survey and experimental data are given in the respective chapters.

CHAPTER THREE: VEGETATION COMPOSITION, ABUNDANCE AND SPECIES RICHNESS

3.1 Introduction

Environmental conditions, habitat degradation, introduction or loss of exotic species and other factors are important in determining the distribution and function of biodiversity (Mackey, 2007). Changes in long term environmental conditions, termed climate change, can have significant impacts on plant diversity patterns (Sahney *et al*. 2010). This is especially important in floodplains where climate variability alters flood regimes, influencing plant community structure. It has been postulated that if climate factors change beyond the tolerance of species phenotypic plasticity, then distribution changes of the species may be inevitable (Lynch & Lande, 1993). The survival of species is determined by all the drivers of biodiversity change acting in synergy with each other (Mackey, 2007). Plants, like all other living organisms, perform best under favourable conditions (Iwara *et al*. 2011). This accounts for their differences in distribution and abundance.

A number of studies (Walker & Noy Meir, 1982; Frost *et al*. 1986; Scholes & Archer, 1997; Ehrenfeld, 2003) have established patterns in abundance and structure of plant communities in African savannas. Although there are questions yet to be answered, many agree that rainfall, fire, herbivory and resource-competition interact and operate at various spatial and temporal scales to structure savanna ecosystems. Other modifiers of plant community composition include, climate (Lovejoy & Hannah, 2006), invasive alien species (Levine *et al*. 2003; Brooks *et al*. 2004; Getachew *et al.* 2012), grass competition in nutrient-rich savannas (Riginos, 2009) and flood disturbances (Amoros & Bornette, 2002; Child *et al.* 2010).

Sampling of vegetation should consider land use types and natural resource utilisation, which are driven by human needs (Agea *et al*. 2010). This is because such a consideration enables land use practices to be integrated into management plans for sustainable utilisation of natural resources. Land use changes, competitive ecological advantages and climate change are also thought to be key factors influencing the probability of biological invasion (Pasiecznic *et al*. 2001). Moreover, land use activities such as grazing cause disturbances, which can lead to bush encroachment (Polley *et al*. 2002) and invasion (Pasiecznic *et al*. 2001). The disturbances can upset the tree-grass ratio, which is crucial for survival of both wildlife and livestock in savanna ecosystems.

A number of factors could be responsible for influencing plant species abundance and diversity in Tana River County. These factors include climate variability which influences flooding regimes and droughts, soil nutrient levels, degree of invasion principally by *Prosopis juliflora*, habitat conditions and land use practices which tend to disturb the natural ecosystem. *Prosopis* species are invasive and more resistant to drought than indigenous species (Olukoye *et al*. 2003) and thus have an advantage compared to the latter species. Exotic plant species invade and change the structure of savanna ecosystems (Brooks *et al*. 2004) and cause loss of native plant biodiversity (Levine *et al*. 2003; Getachew *et al.* 2012). Cultivation in this region is practiced mainly in the floodplain using flood water and outside the floodplain mainly in Bura and Hola irrigation schemes using water from Tana River. Pastoralism is also practiced but mainly outside the floodplain except during drought when pastoralists venture inside the floodplain which has more resources for their livestock. Although floods provide water that is critical in arid and semi-arid regions, flood water can also disperse propagules of invasive plant species and provide nutrient rich conditions that enhance their regeneration (Howell & Benson, 2000). Pastoralism can also enhance plants invasion in floodplains if this sudden influx of resources combines with disturbances caused by livestock grazing.

Land use types are likely to cause changes in the composition, abundance and diversity of plants in the study area. Livestock grazing and irrigated agriculture can cause disturbances that negatively impact plant community structure. Although livestock dung can fertilize soils and promote regeneration and growth of plants, overgrazing can lead to degradation of soils, which can have a negative impact on vegetation. Livestock grazing can also enhance encroachment by woody plant species due to reduced competition of woody plant seedlings with established grass. Land clearance is necessary for irrigated agricultural farming to be effected. Moreover, trees or their branches are cut down to allow light penetration which enhances growth of food crops. These anthropogenic activities can degrade the environment and interfere with the natural vegetation, unlike in wildlife conservation areas where disturbance is minimal. On the other hand, Climate variability and construction of dams along Tana River alters flood regimes, which can influence plant community structure in the floodplain. Floods can lead to extreme variations in soil nutrients and moisture, increased competition with non-indigenous species and exacerbate the effects of disturbances caused by grazing.

It is within this background that this part of the study was conceptualized to determine the vegetation dynamics in Tana River County as influenced by cross-sectional floodplain gradient and disturbances.

3.2 Objectives

The main objective was to determine the variation in population structure of plant species with cross-sectional floodplain gradient and across the main land use types. The specific objectives were:

- To determine the plant species composition, abundance and richness on and off the floodplain
- To determine the composition, abundance and richness of plant species in wildlife conservation, livestock grazing and irrigated agricultural areas

3.3 Materials and Methods

Vegetation data were collected along 100m line transects, which ran perpendicular to the river, the exact direction of transects depended on the direction of the river meanders. Each transect was divided into 10m segments and two segments were selected randomly for sampling. Each of the two selected segments formed one side of a 10m x 10m plot. The 10m x 10m plot was the sampling unit used for measuring trees and large shrubs (> 31.4cm circumference at breast height), small shrubs (< 31.4cm circumference at breast height) and saplings (6-13cm circumference at breast height) from 5m x 5m plots nested in the 10m x 10m plots. Seedlings (< 6cm circumference), Forbs (herbs) and perennial grasses were measured using three 0.5m x 0.5m quadrats placed randomly within the 5m x 5m plot. The information collected included species name and number of all plants sampled, circumference at breast height and canopy cover of tree species. The trees, shrubs, saplings, seedlings, forbs, perennial grasses in the respective plots and quadrats were identified and counted. Verification of species identity was done at the University of Nairobi herbarium for those species that were not readily identifiable in the field. The tree, shrub and sapling densities were calculated per hectare whereas the seedling, forb and perennial grass densities were calculated per m^2.

The canopy cover of trees was determined in m^2 by measuring the crown width in the N- S direction and that in the E-W direction using a tape then multiplying them. The basal area of a tree is the cross-sectional area of a tree at breast height, and can be calculated from the diameter at breast height (DBH), estimated at 1.3m above ground level. However, rather than the diameter, the circumference at breast height was measured using a flexible tape and used to determine the basal area of the trees. Basal area was then determined in m^2 using the formula; $A = 0.0796\ c^2/ 10{,}000$ where c is circumference in cm. The woody vegetation was measured per square hectare and the non-woody vegetation per square meter. Genstat Software 15th Edition (Payne *et al.* 2012), was used to compare the density of vegetation as well as the basal area and canopy cover of trees. Analysis was separate for the woody and non-woody vegetation and the former was analyzed based on the different life-history stages (trees, shrubs, saplings and seedlings).

The relative densities and relative basal areas of tree species were also determined as indicated in the formulae below:

$$\text{Relative density} = \frac{\text{Number of plants by species in plot x 100}}{\text{Total number of plants of all species}}$$

$$\text{Relative basal area} = \frac{\text{Total basal area of all plants of a species x 100}}{\text{Total basal area of all plants}}$$

The importance value (IV 200) was then determined using the two variables calculated above as follows:

IV 200 = Relative density + Relative basal area

3.3.1 Data analysis

The variables assessed were density (trees, shrubs, saplings, seedlings, forbs, and perennial grass), basal area, importance value and canopy cover of trees. The data was collected inside and outside the floodplain based on the main land uses in the study area, i.e. conservation, grazing and irrigated agriculture. All the variable means were compared using t-test for data inside and outside the floodplain and using ANOVA for data from the different land uses. Levene's test was used to test for homogeneity of variance across the different samples. Test results were considered significant at significance level of 5% or less.

3.4 Results

3.4.1 Vegetation abundance and richness inside and outside the floodplain

Sampling was done in a total of 62 transects (31 inside and 31 outside the floodplain). The transects inside the floodplain were not spatially paired with those outside. Three groups of species were separated; those that occur in the floodplain only, those outside the floodplain only and those both inside and outside. This was done in order to determine if floods influenced the abundance and richness of the vegetation inside the floodplain. Overall, a total of 100 woody plant species were identified; 48 tree species and 52 shrub species whereas a total of 51 non-woody species were identified; 41 herbs and 10 perennial grass species. The details of the results are presented in different sections below.

3.4.1.1 Variation in tree species richness and density

There were 35 tree species inside the floodplain compared to 24 tree species outside the floodplain (figure 3.1a). Of these tree species, 24 were found only inside the floodplain (figure 3.1b), 13 only outside the floodplain (figure 3.1c) and 11 both inside and outside the floodplain (table 3.1). The tree species inside the floodplain were identified in 18 transects whereas those outside the floodplain were identified in 13 transects.

The overall mean densities of trees inside and outside the floodplain were 350±63 and 285±37 plants/ha respectively. However, the difference between their mean density was not significant ($t_{(108)} = 0.87$, $P = 0.39$). The mean densities and standard errors of the tree species found only inside and only outside the floodplain were as shown in figures 3.1b and 3.1c respectively. The range in densities of the tree species found only inside the floodplain was between 850±650 plants/ha represented by *Rinorea elleptica* to 100±0 plants/ha represented by eight species (figure 3.1b). The density range of the tree species found only outside the floodplain was between 300±100 plants/ha represented by *Commiphora riparia* to 100±0 plants/ha represented by five species (figure 3.1c). Among the 11 tree species that occurred both inside and outside the floodplain (table 3.1), *Prosopis juliflora* had the highest mean density of 1825±259 plants/ha which was significantly higher than its density outside the floodplain. The tree species whose densities were higher outside compared to inside the floodplain were *Acacia tortilis, Acacia zanzibarica, Salvadora persica, Dobera glabra, Dobera loranthifolius* and *Maerua pubescence. Salvadora persica* had the highest mean density followed closely by *Acacia tortilis.*

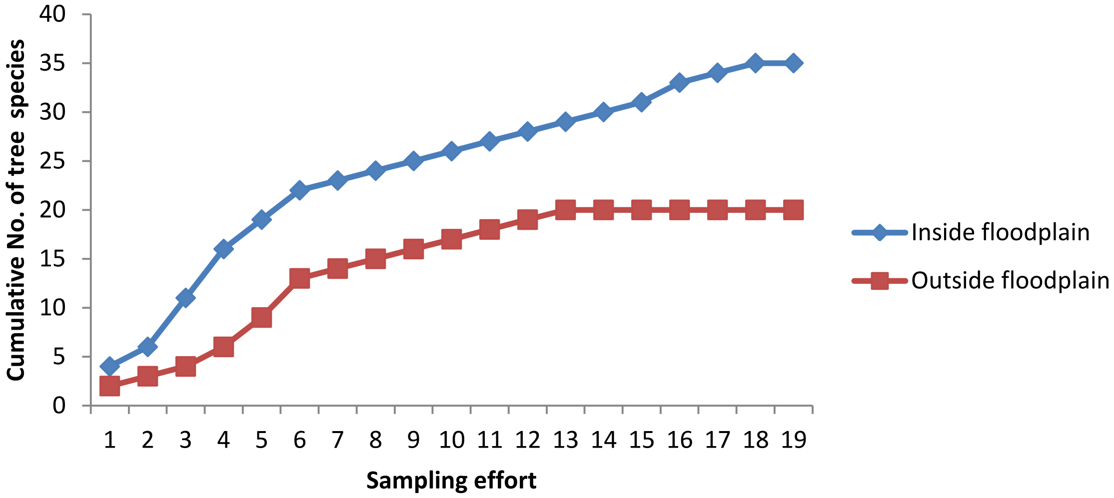

Figure 3.1a: Cumulative number of tree species inside and outside the floodplain.

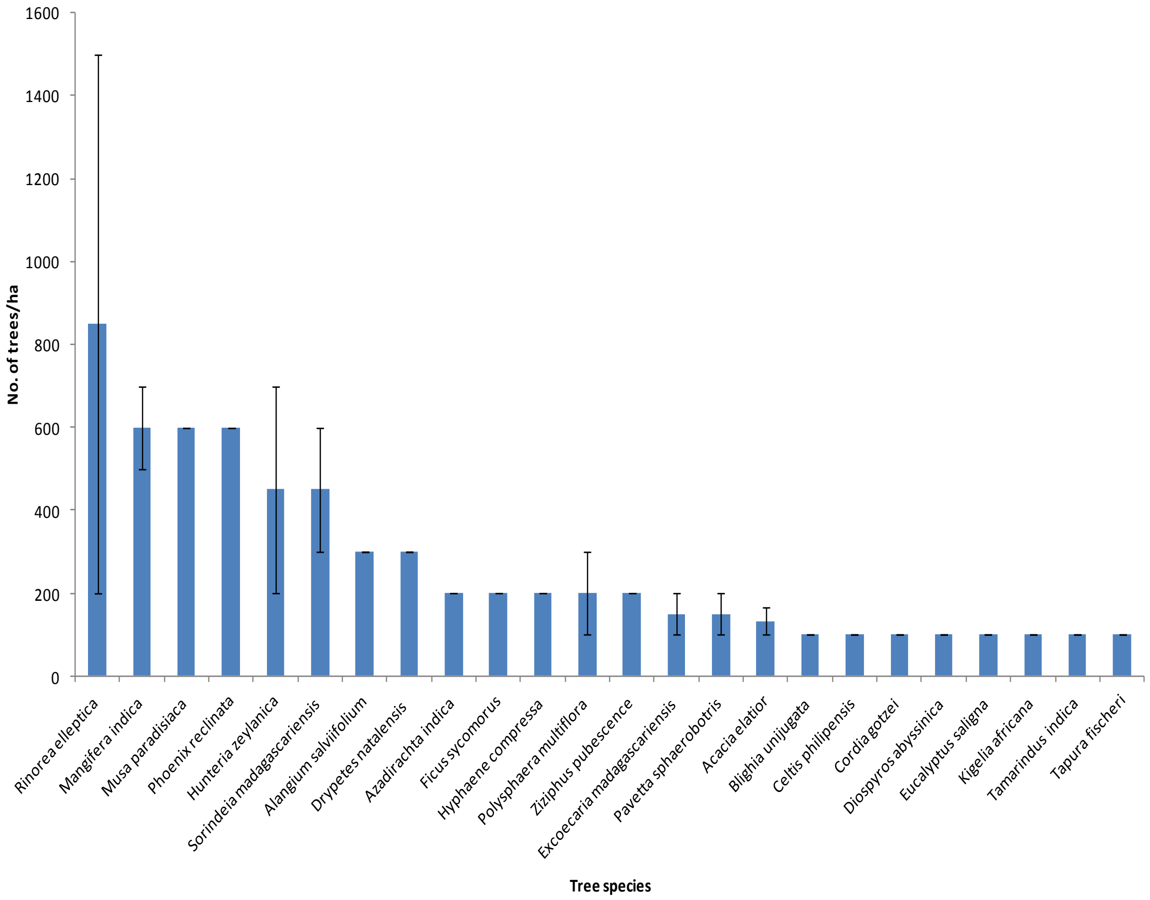

Figure 3.1b: Mean (±SE) densities of tree species found only inside the floodplain. Standard error (SE) bars are missing in cases where there was no variation in density.

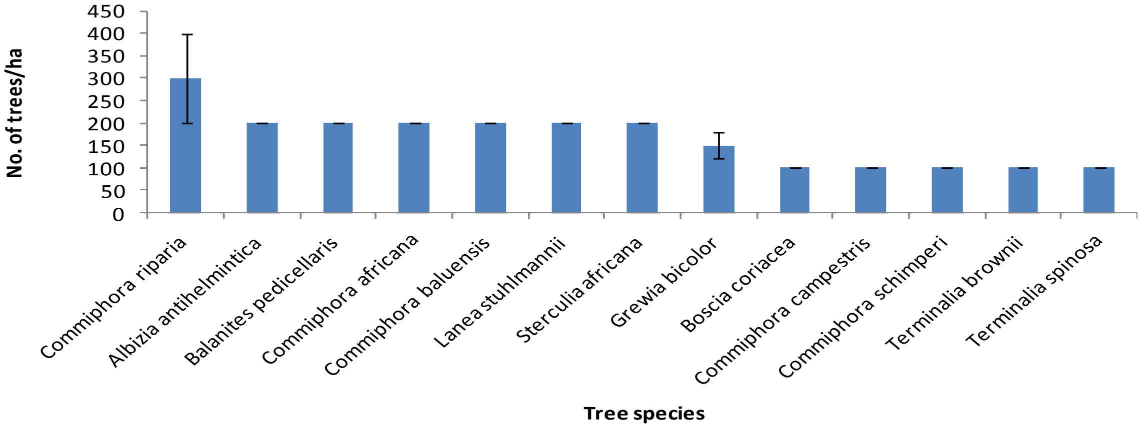

Figure 3.1c: Mean (±SE) densities of tree species found only outside the floodplain. Standard error (SE) bars are missing in cases where there was no variation in density.

Table 3.1: Comparison of mean densities (Mean±SE) of tree species found both inside and outside the floodplain, ±0 means there was no variation in density.

Species	In floodplain	Outside floodplain	t- value	P - value
Acacia nilotica	100±0	400±0	-	-
Acacia robusta	150±50	100±0	1.00	0.42
Acacia tortilis	200±100	500±253	-0.70	0.51
Acacia zanzibarica	267±33	300±0	-0.78	0.50
Dobera glabra	150±50	275±75	-1.08	0.34
Dobera loranthifolius	100±0	200±0	-	-
Lecaniodiscus fraxinifolius	200±100	100±0	0.45	0.69
Maerua pubescence	100±0	240±117	-0.49	0.65
Prosopis juliflora	1825±259	460±93	5.44	0.00**
Salvadora persica	100±0	520±174	-1.44	0.21
Terminalia parvula	200±0	150±50	0.58	0.67

Key: ** = $P < 0.01$

3.4.1.2 Variation in shrub species richness and density

Unlike the trees, the cumulative number of shrub species was higher outside the floodplain than inside, with 37 shrub species outside and 22 inside the floodplain (figure 3.2a). The shrub species outside the floodplain were found in 21 transects whereas those inside the floodplain were in 14 transects. The number of shrub species found only inside the floodplain were 15 (figure 3.2b), those found only outside 30 (figure 3.2c) and those found both inside and outside the floodplain 7 (table 3.2).

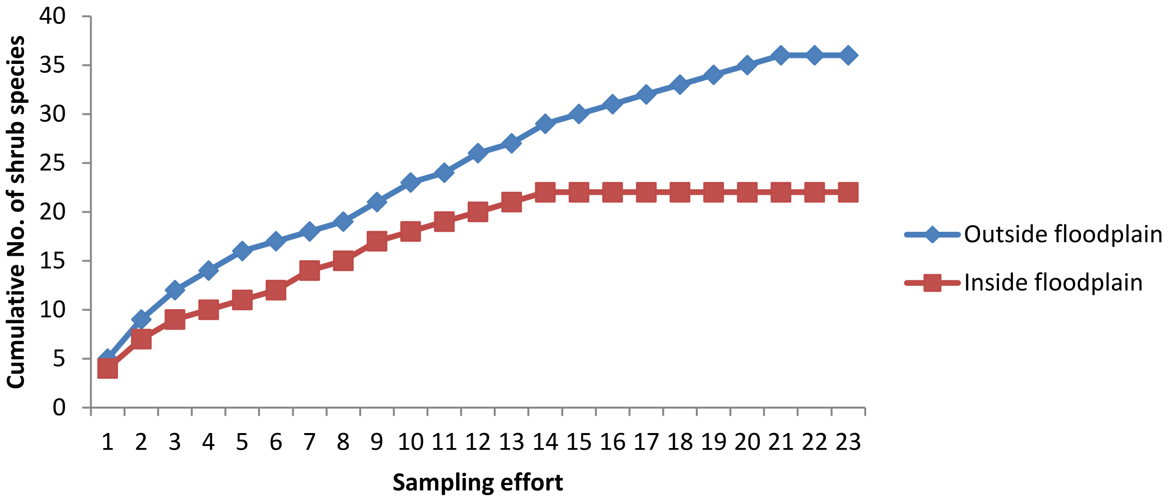

Figure 3.2a: Cumulative number of shrub species inside and outside the floodplain.

The overall density means of shrubs inside and outside the floodplain were 1540±257 and 1160±104 per hectare respectively. However, there was no significant difference ($t_{(118)} = 1.63$, $P = 0.11$) between the density of shrubs inside the floodplain compared to outside the floodplain. The shrub species that were found only inside the floodplain and only outside the floodplain were as shown in figures 3.2a and 3.2b respectively. The range in the density of the shrub species found inside the floodplain only was 2533±706 plants/ha represented by *Thespesia danis* to 400±0 plants/ha represented by ten shrub species (figure 3.2a). Outside the floodplain the density ranged from 2800±1058 plants/ha represented by *Salsola dendroides* to 400±0 plants/ha represented by eleven shrub species (figure 3.2b). Of the shrub species found both inside and outside the floodplain (table 3.2), the mean densities of *Cordia sinensis* and *Grewia tembensis* were higher outside than inside the floodplain. The densities of all the other shrub species were higher inside compared to outside the floodplain. *Barleria taitensis* had the highest density inside whereas *Grewia tembensis* had the highest density outside the floodplain. There was however no significant difference between the density of any of the shrub species occurring both inside and outside the floodplain.

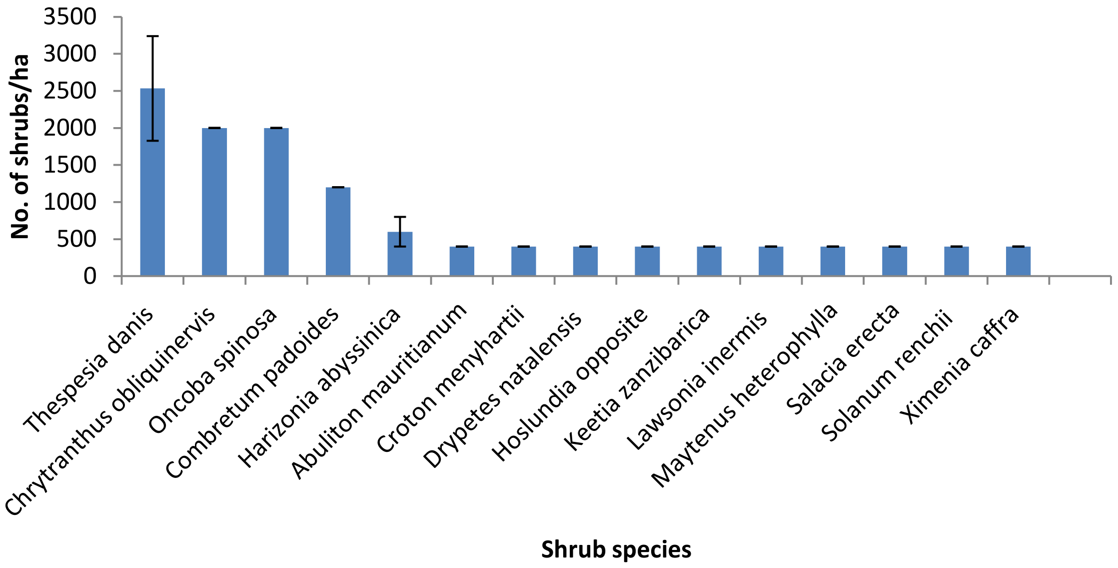

Figure 3.2b: Mean (±SE) density of shrub species found only inside the floodplain. Standard error (SE) bars are missing where the standard error of the species was zero.

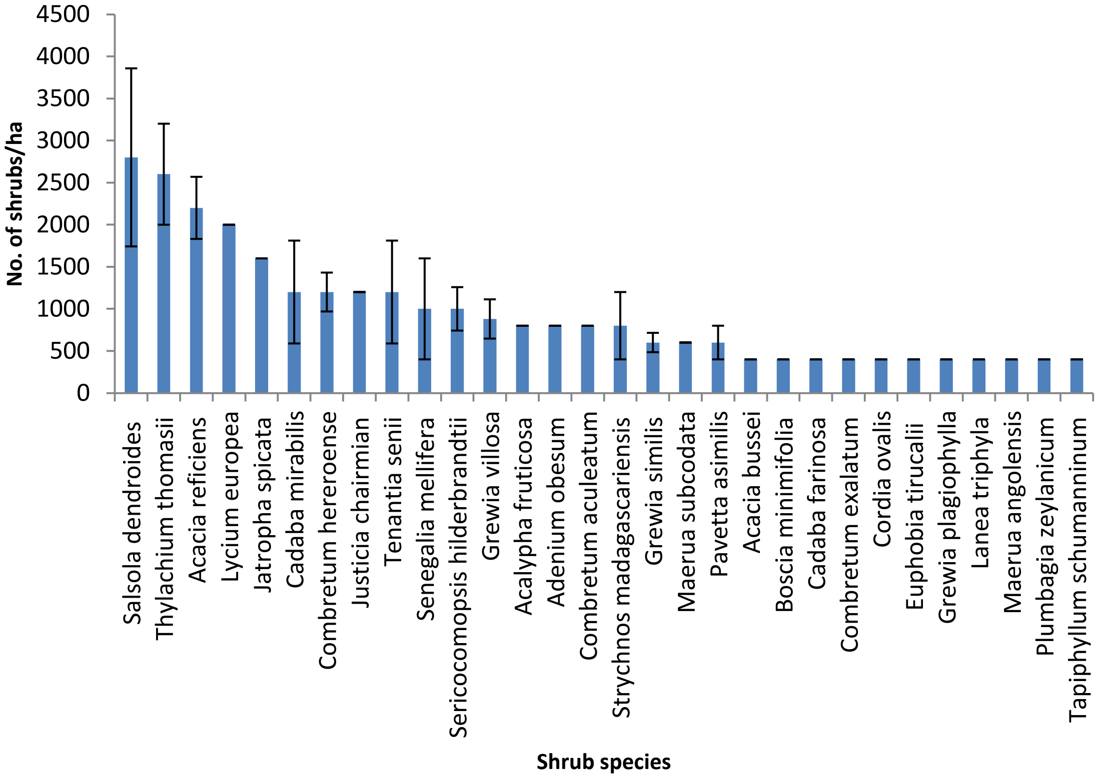

Figure 3.2c: Mean (±SE) density of shrub species found only outside the floodplain. Standard error (SE) bars are missing where the standard error of the species was zero.

Table 3.2: Comparison of density means (Mean±SE) of shub species found both inside and outside the floodplain, ±0 means there was no variation in the species density. No significant differences in some species with high t-values was due to the high variance in their densities.

Species	In floodplain	Outside floodplain	t- value	P - value
Barleria taitensis	4000±1600	400±0	1.13	0.38
Cordia sinensis	533±133	1100±473	-0.99	0.37
Grewia tembensis	400±0	2100±681	-1.12	0.35
Grewia tenax	1200±0	1120±388	0.08	0.94
Indigofera lupatana	2400±2000	400±0	0.58	0.67
Phyllanthus ovalifolius	3440±627	1733±353	1.95	0.10
Phyllanthus sepialis	1600±693	400±0	0.87	0.48

3.4.1.3 Variation in woody species sapling richness and density

The cumulative number of woody species saplings was higher outside (29 species) than inside the floodplain (24 species), found in 20 and 17 transects outside and inside the floodplain respectively (figure 3.3a).

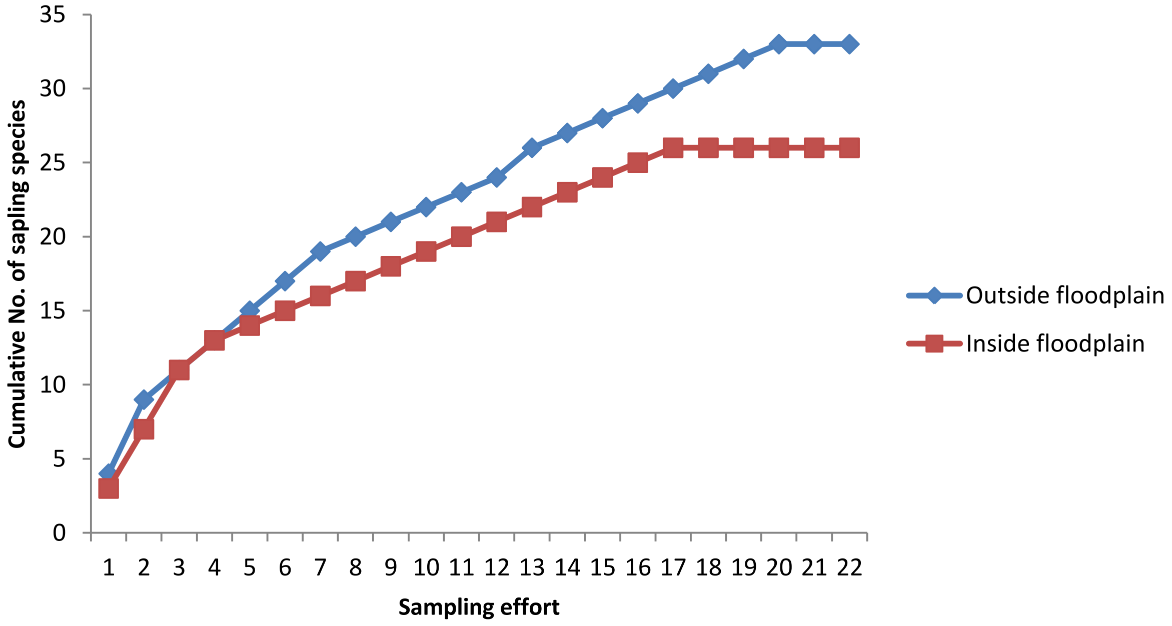

Figure 3.3a: Cumulative number of woody species saplings inside and outside the floodplain.

The overall density means inside and outside the floodplain were 2550±410 and 1742±377 saplings/ha respectively. However, there was no significant difference in the density of woody species saplings ($t_{(108)} = 1.44$, $P = 0.15$) inside and outside the floodplain. The mean densities of saplings that were found only inside the floodplain and only outside the floodplain were as shown in figures 3.3b and 3.3c respectively. The range in the density of woody species saplings inside the floodplain was between 6400±0 saplings/ha represented by *Ricinus communis* to 400±0 saplings/ha represented by four species (figure 3.3b). Outside the floodplain the density of woody species saplings ranged between 6960±2807 saplings/ha represented by *Boscia coriacea* to 400±0 saplings/ha represented by nine species (figure 3.3c). Of the woody species saplings found both inside and outside the floodplain (table 3.3), the densities of most woody plant saplings were higher inside compared to outside the floodplain. The exceptions were *Dobera glabra* and *Phyllanthus ovalifolius* whose densities were higher outside the floodplain. The mean density of *Prosopis juliflora* was highest compared to that of the other saplings both inside and outside the floodplain. However, there was no significant difference between the density of *Prosopis juliflora* inside and outside the floodplain.

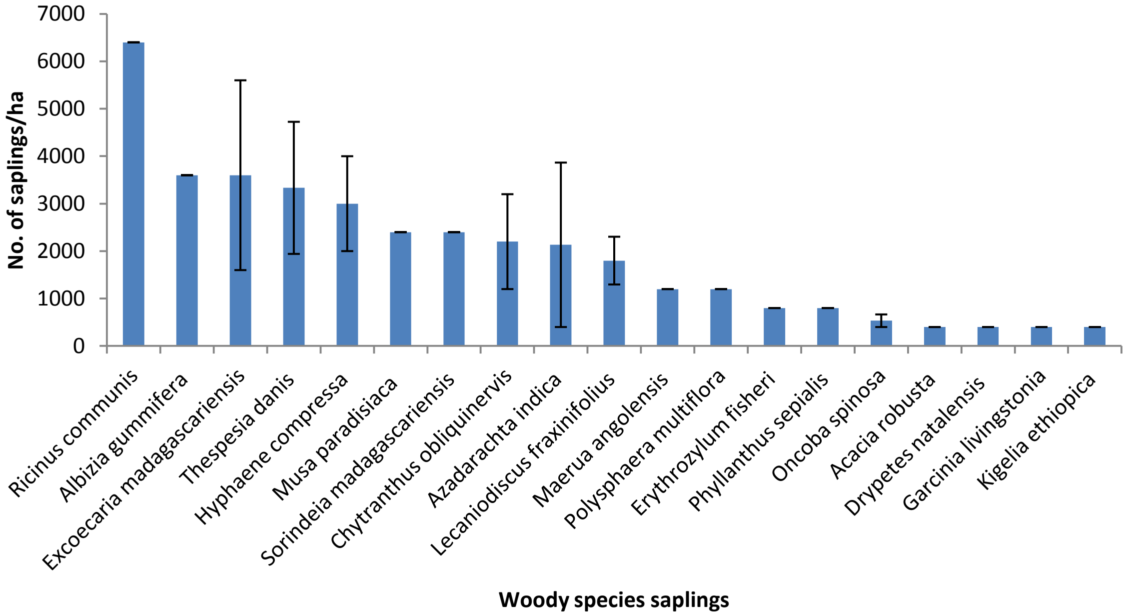

Figure 3.3b: Mean (±SE) densities of woody species saplings found only inside the floodplain. Standard error (SE) bars are missing in cases where the standard error of the species was zero.

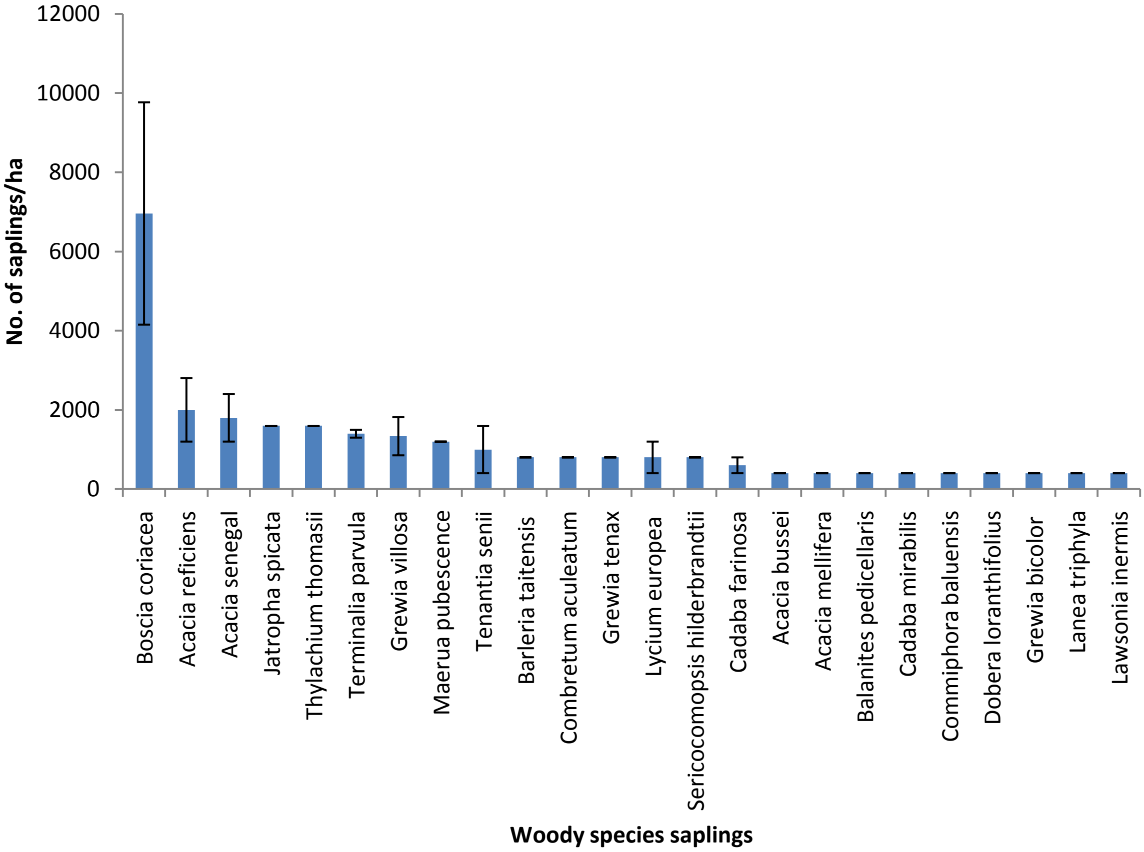

Figure 3.3c: Mean (±SE) densities and standard errors of woody species saplings found only outside the floodplain. Standard error (SE) bars are missing in cases where the standard error of the species was zero.

Table 3.3: Comparison of Mean ±SE density of woody species saplings found both inside and outside the floodplain, ±0 means there was no variation in density. A high t-value and no significance (high P-value) implied a high variance in density.

Species	In floodplain	Outside floodplain	t- value	P - value
Acacia zanzibarica	533±133	400±0	0.78	0.5
Cordia sinensis	2200±200	400±0	5.20	0.12
Dobera glabra	1200±0	1760±601	-0.38	0.72
Phyllanthus ovalifolius	3400±200	4800±0	-4.04	0.15
Prosopis juliflora	8160±2084	5500±3008	0.75	0.48

3.4.1.4 Variation in woody species seedling richness and density

The number of woody species seedlings was 11 and 9 outside and inside the floodplain respectively (figure 3.4a). The seedlings were found in 8 and 7 transects outside and inside the floodplain respectively out of the 31 transects along which sampling was done in each case.

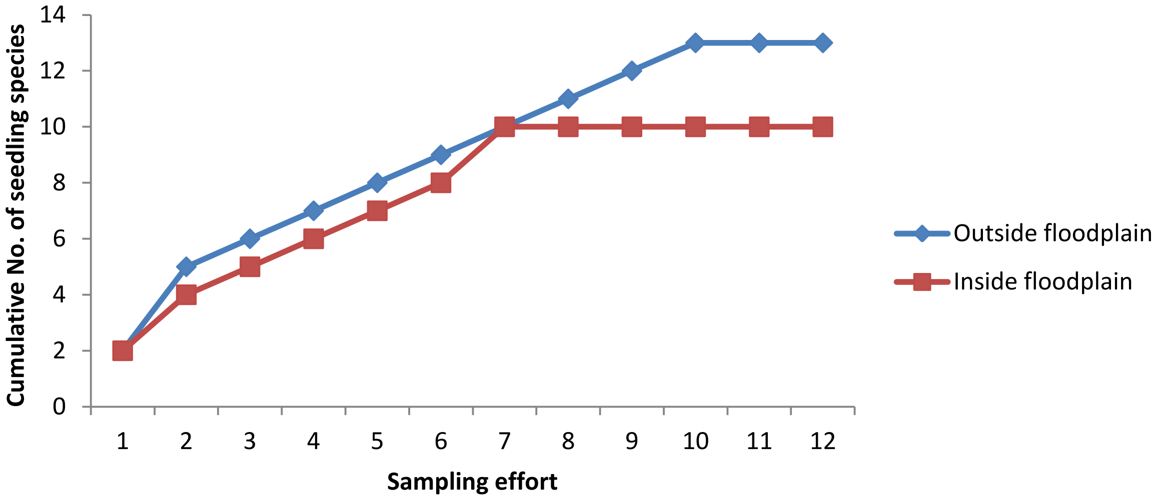

Figure 3.4a: Cumulative number of woody species seedlings inside and outside the floodplain.

The overall density means of woody species seedlings were 31±10 and 14±3 per square meter inside and outside the floodplain respectively and the difference in densities was not significant ($t_{(50)}$ = 1.860, P = 0.069). The mean densities of seedlings found only inside and only outside the floodplain were as shown in figures 3.4b and 3.4c respectively. The density of woody species seedlings inside the floodplain ranged from 88±35 seedlings/m^2 represented by *Acacia elatior* to 4±0 seedlings/m^2 represented by *Acacia zanzibarica, Drypetes natalensis, Hunteria zeylanica* and *Lecaniodiscus fraxinifolius*. The density range outside the floodplain was between 30±10 seedlings/m^2 represented by *Acacia reficiens* to 4±0 seedlings/m^2 represented by *Balanites pedicellaris* and *Commiphora baluensis* seedlings. Of the woody species seedlings found both inside and outside the floodplain (table 3.4), the density of *Prosopis juliflora* (27±8 seedlings/m^2) was higher inside than outside the floodplain, whereas the density of C*ordia sinensis* (11±5 seedlings/m^2) was higher outside than inside the floodplain. Both inside and outside the floodplain, *Prosopis juliflora* seedlings recorded the highest mean density compared to the density of the other seedlings.

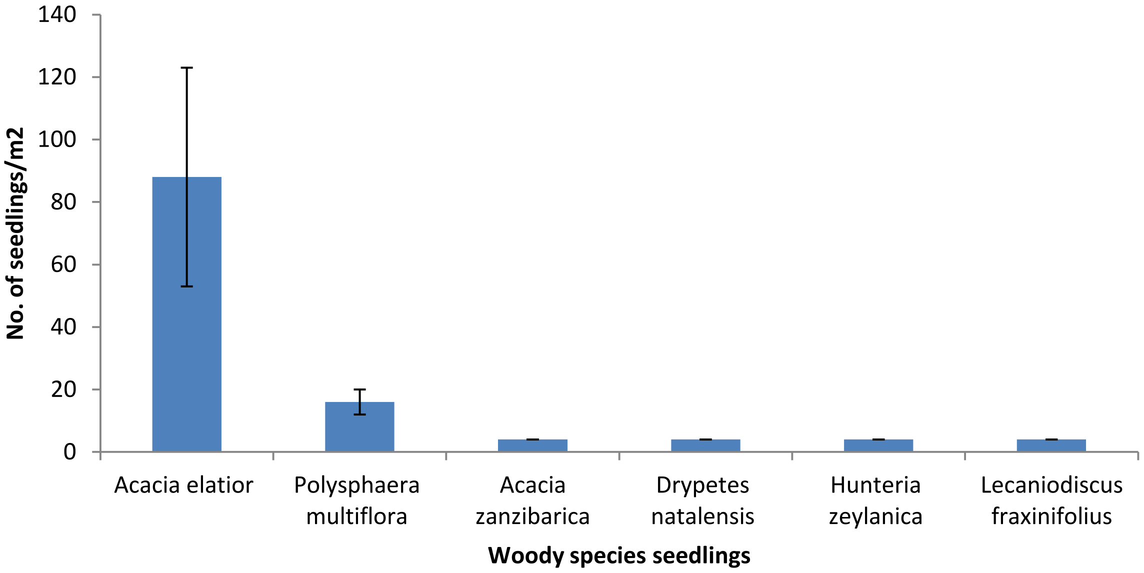

Figure 3.4b: Mean densities and standard errors of woody species seedlings found only inside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

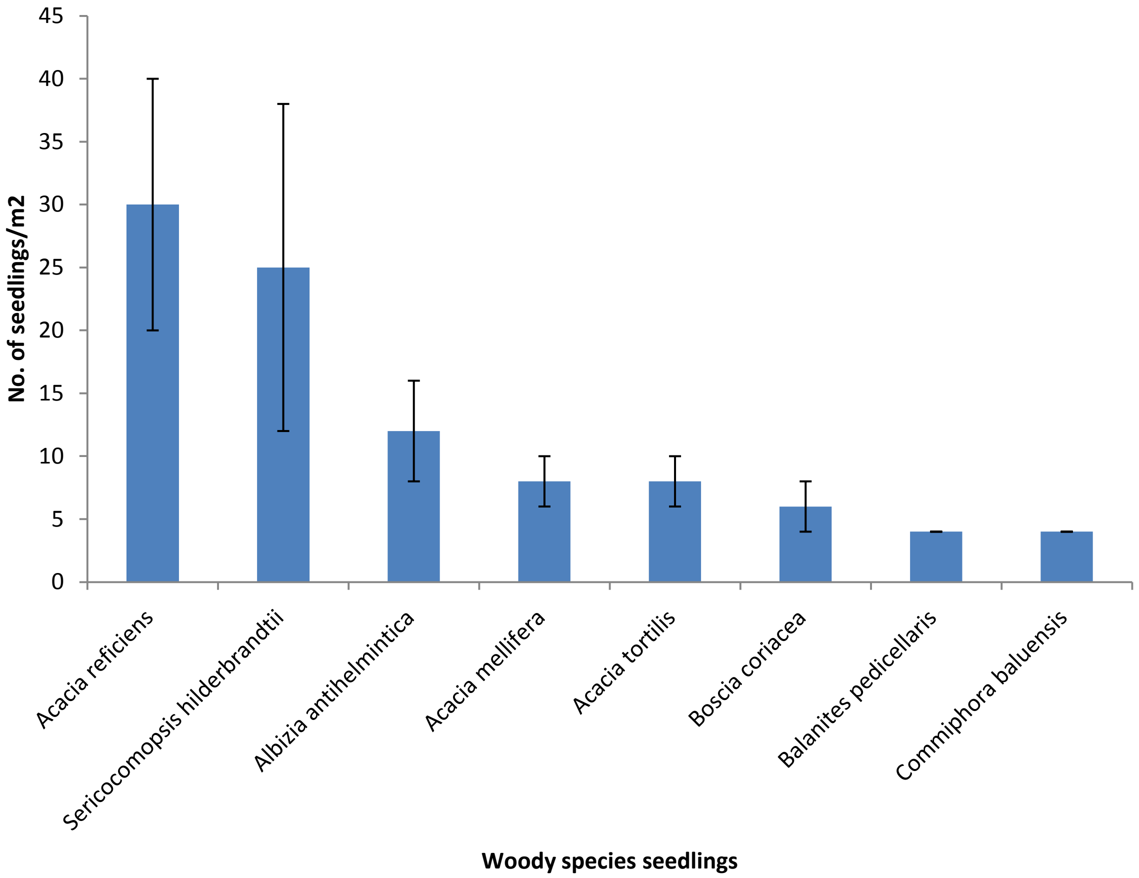

Figure 3.4c: Mean densities and standard errors of woody species seedlings found only outside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

Table 3.4: Comparison of the density of woody species seedlings found both inside and outside the floodplain (Mean±SE), ±0 means no variation in density among species.

Species	In floodplain	Outside floodplain	t-value	P-value
Cordia sinensis	4±0	6±2	-0.58	0.67
Phyllanthus ovalifolius	4±0	4±0	-	-
Prosopis juliflora	27±8	11±5	1.27	0.23

3.4.1.5 Variation in forb richness and density

The cumulative number of forb species was much more outside the floodplain than inside. The number of forb species was 37 outside and 13 inside the floodplain, found in 17 and 10 transects outside and inside the floodplain respectively (figure 3.5a).

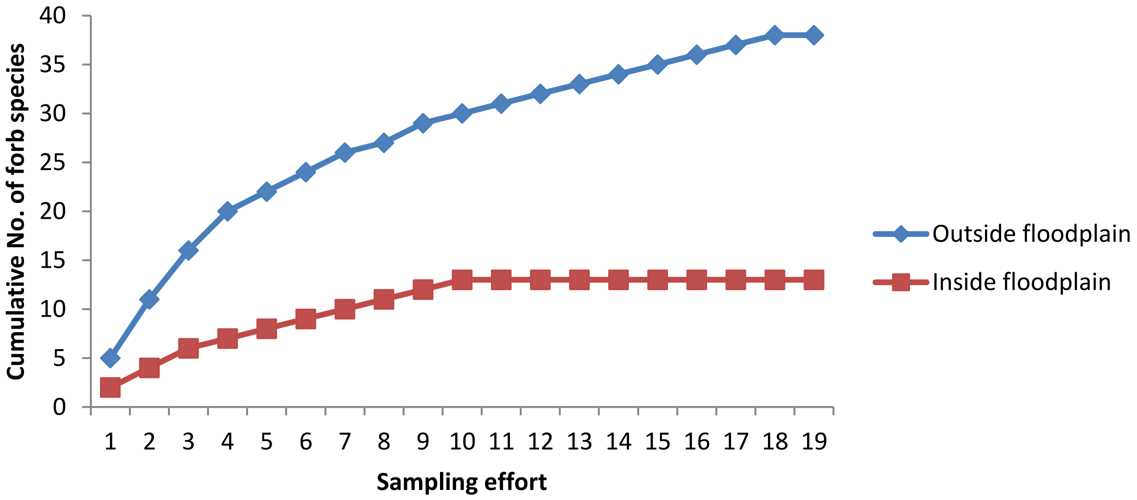

Figure 3.5a: Cumulative number of forb species found inside and outside the floodplain.

There was a significant difference ($t_{(106)} = 4.44$, $P = 0.00$) in the density of forbs inside compared to outside the floodplain, with overall mean densities of 20±5 and 8±1 respectively. The mean densities of the forb species found only inside and only outside the floodplain were as shown in figures 3.5b and 3.5c respectively. The range in forb density inside the floodplain was between 22±10 plants/m^2 represented by *Launea cornuta* to 4±0 plants/m^2 represented by *Gycine javanica* and *Nothosaerva brachiata*. Outside the floodplain, the density of forbs ranged between 16±0 plants/m^2 represented by *Sida acuta* to 4±0 plants/m^2 represented by sixteen forb species (figure 3.5c). The densities of *Pupalia lapacea, Ruelia megachlamys* and *Ruelia patula* were higher outside than inside the floodplain (table 3.5), the former having the highest density. The densities of all the other forbs were higher inside than outside the floodplain, with *Justicia flava* having the highest density followed closely by *Commelina benghalensis.* The densities of *Commelina benghalensis* and *Justicia flava* were significantly higher inside the floodplain compared to outside.

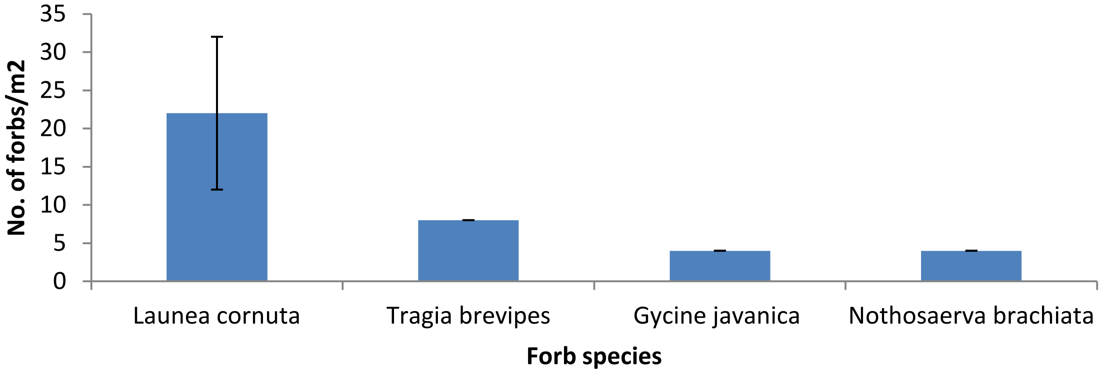

Figure 3.5b: Mean densities and standard errors (Mean±SE) of forbs found only inside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

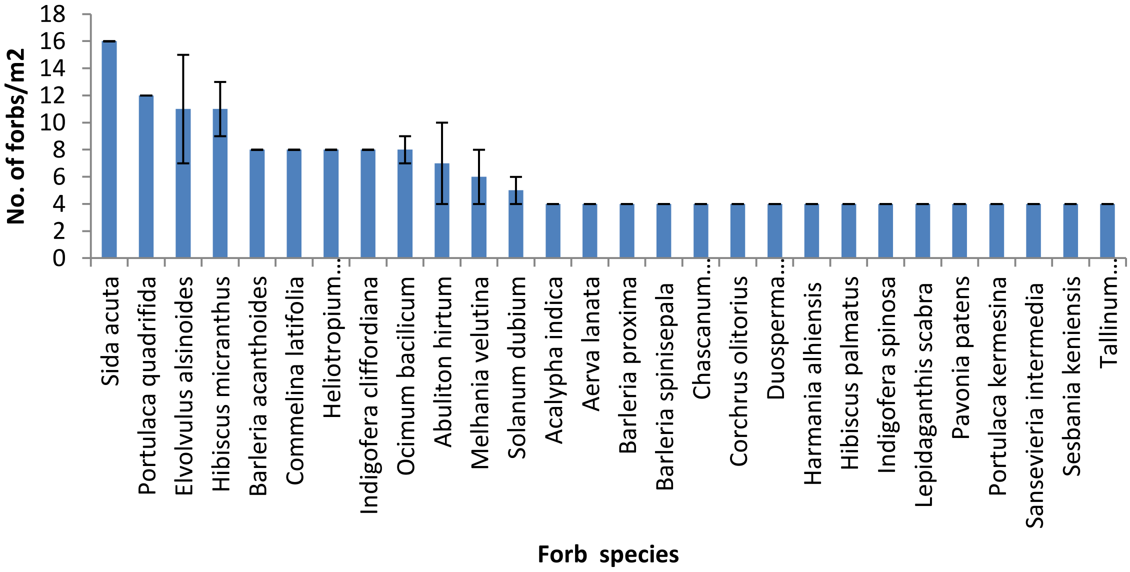

Figure 3.5c: Mean densities and standard errors (Mean±SE) of forbs found only outside the floodplain. Standard error bars are missing where the standard error of the species was zero.

Table 3.5: Comparison of mean densities (Mean±SE) of forbs found both inside and outside the floodplain, ±0 means there was no variation in density.

Species	In floodplain	Outside floodplain	t-value	P-value
Abuliton mauritianum	4±0	4±0	-	-
Borreria stricta	16±0	8±0	-	-
Commelina benghalensis	52±0	5±1	21.02	0.00**
Indigofera schimperi	14±10	4±0	1.63	0.18
Justicia declipteroides	12±0	7±3	2.00	0.12
Justicia flava	59±15	6±2	4.21	0.01**
Pupalia lapacea	14±2	19±5	-0.44	0.67
Ruelia megachlamys	4±0	17±7	-0.90	0.46
Ruelia patula	4±0	16±0	-	-

Key: ** = $P \leq 0.01$

3.4.1.6 Variation in perennial grass species richness and density

The cumulative number of perennial grass species was seven and eight species inside and outside the floodplain respectively (figure 3.6). However, these were found in six transects inside the floodplain and in only four transects outside the floodplain. Most of the perennial grass species outside the floodplain were found along only one transect (five species), with one new species being found in three other transects out of the total of 31 transects.

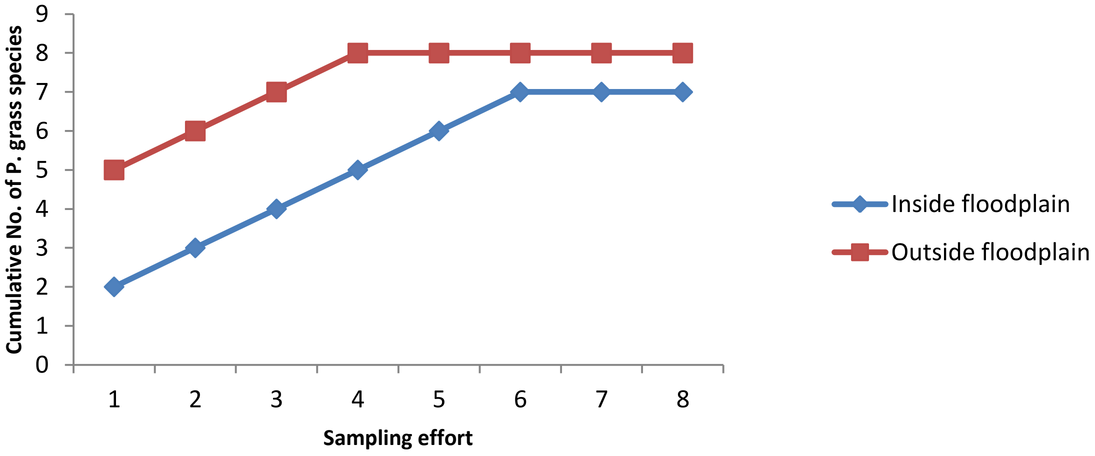

Figure 3.6a: Cumulative number of perennial grass species inside and outside the floodplain.

There was a significant difference in the density of perennial grasses ($t_{(58)}$ = 2.33, P = 0.02) inside the floodplain compared to outside the floodplain, with overall means of 45±12 and 22±4 plants/m^2 respectively. The perennial grasses found only inside the floodplain were *Cenchrus ciliaris* (4±0 plants/m^2) and *Eraglostis superba* (10±6 plants/m^2) whereas those found only outside were *Chloris roxburghiana* (8±2 plants/m^2), *Latipes senegalensis* (6±2 plants/m^2) and *Tetrapogon bidentatus* (14±4 plants/m^2). For the perennial grasses found both inside and outside the floodplain (table 3.6), the mean density of *Cynodon dactylon* was highest in both cases compared to that of other perennial grasses and significantly higher inside the floodplain.

Table 3.6: Comparison of density (Mean±SE) of perennial grass found both inside and outside the floodplain, ±0 means there was no variation in density. A high t-value but not significant P-value means high variance in the density.

Species	In floodplain	Outside floodplain	t-value	P-value
Cynodon dactylon	96±18	42±10	2.69	0.02*
Echinochloa pyramidalis	13±3	7±1	1.40	0.21
Enteropogon macrostachyus	4±0	24±7	-0.92	0.39
Sporobolus helvolus	16±0	10±2	3.00	0.10
Panicum maximum	40±0	40±0	-	-

Key: * = P < 0.05

3.4.1.7 Variation in the basal areas of trees

There was a very significant difference in the basal area of trees ($t_{(349)}$ = -4.54, P = 0.00) between inside and outside the floodplain. The overall mean basal area of trees was lower inside the floodplain compared to outside the floodplain (6.6±0.5 and 13.2±1.6 m^2 per hectare respectively). The mean basal areas and standard errors of the tree species found either inside the floodplain or outside the floodplain were as shown in figures 3.7a and 3.7b respectively. *Tamarindus indica* had the highest basal area of 17.9m^2/ha whereas *Blighia unijugata* had the lowest mean basal area of 0.3m^2/ha. Outside the floodplain, *Commiphora campestris* had the highest mean basal area of 53m^2/ha and *Commiphora schimperi* the lowest with 1.0m^2/ha.

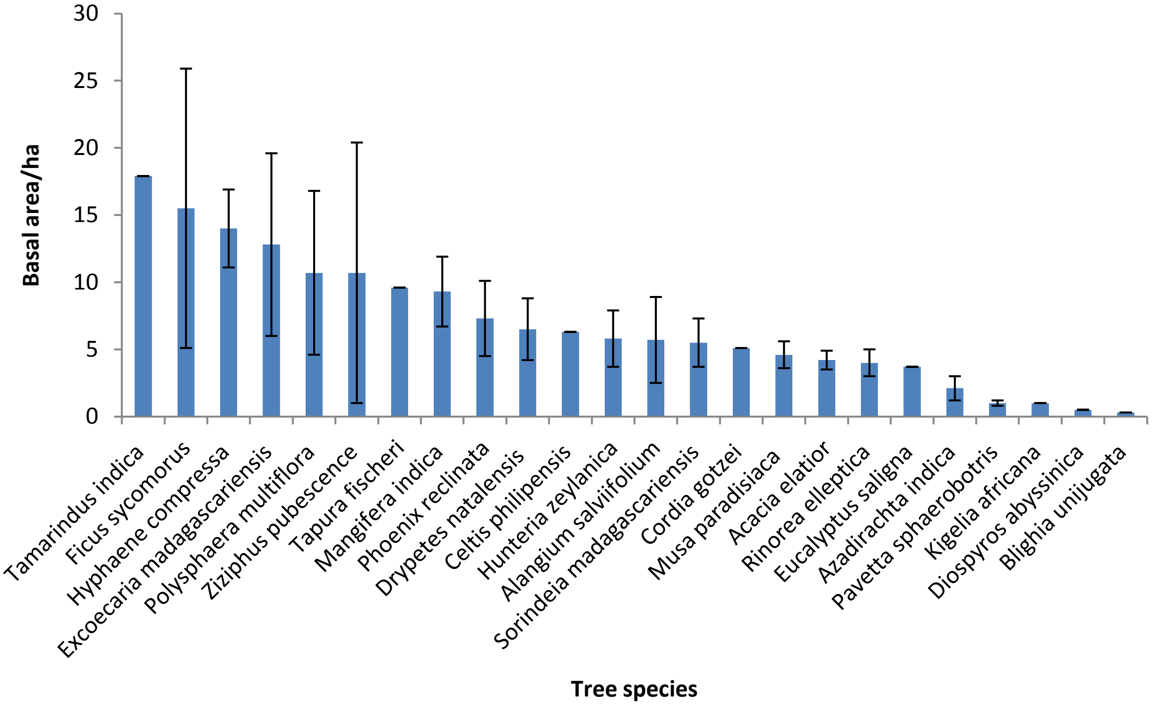

Figure 3.7a: Mean basal area and standard errors (Mean±SE) of tree species found only inside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

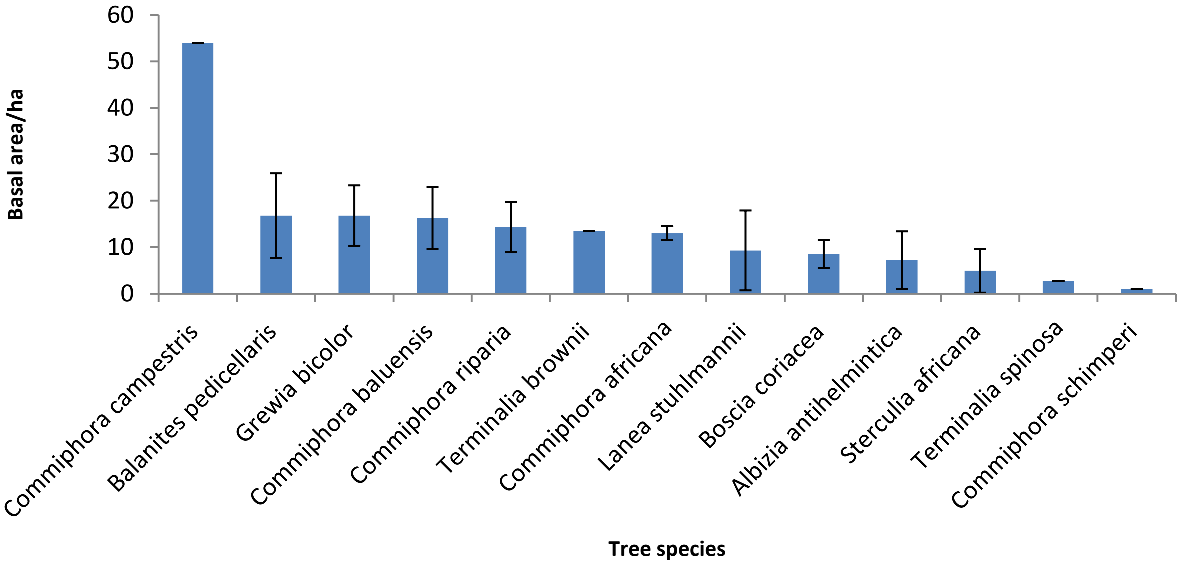

Figure 3.7b: Mean basal area and standard errors (Mean±SE) of tree species found only outside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

Of the tree species found both inside and outside the floodplain (table 3.7), the mean basal areas of *Acacia robusta*, *Acacia nilotica* and *Lecaniodiscus fraxinifolius* were higher inside compared to outside the floodplain. The former species had the highest mean basal area of followed closely by the latter species. All the other tree species had mean basal areas that were higher outside compared to inside the floodplain. The mean basal area of *Dobera loranthifolius* was the highest, followed closely by *Terminalia parvula* then *Dobera glabra*. Although the mean basal area of *Prosopis juliflora* was much lower than that of most of the tree species found outside the floodplain, it was significantly higher than its mean basal area inside the floodplain.

Table 3.7: Comparison of basal areas (Mean±SE) of tree species found both inside and outside the floodplain, ±0 means there was no variation in basal area.

Species	In floodplain	Outside floodplain	t-value	P- value
Acacia nilotica	6.0±0.0	2.1±1.1	1.64	0.20
Acacia robusta	13.9±12.3	5.4±1.0	0.53	0.63
Acacia tortilis	4.1±3.1	16.5±6.0	-0.81	0.43
Acacia zanzibarica	2.1±0.4	8.2±3.7	-1.95	0.08
Dobera glabra	8.4±2.6	23.1±9.4	-0.79	0.44
Dobera loranthifolius	9.6±0.0	24.4±21.5	-0.40	0.76
Lecaniodiscus fraxinifolius	13.5±6.1	4.2±0.0	0.51	0.63
Maerua pubescence	2.0±0.0	11.5±73.5	-0.76	0.46
Prosopis juliflora	5.6±0.7	10.0±2.6	-2.24	0.03*
Salvadora persica	8.6±3.6	10.7±2.3	-0.25	0.80
Terminalia parvula	9.3±4.2	23.5±19.5	-0.56	0.62

Key: * = $P < 0.05$

3.4.1.8 Variation in the canopy covers of trees

There was a very significant difference in the canopy cover of trees ($t_{(349)} = -3.87$, $P = 0.00$) between inside and outside the floodplain. Like the basal area, the overall canopy cover of trees was lower inside compared to outside the floodplain (mean 53.7±4.0 and 83.0±7.0 m^2

per hectare respectively). The mean canopy covers of tree species found either inside or outside the floodplain were as shown in figures 3.8a and 3.8b respectively. *Tapura fischeri* had the highest mean canopy cover inside the floodplain with 262.4m^2/ha whereas *Pavetta sphaerobotris* had the lowest with 8.0m^2/ha. Outside the floodplain, *Commiphora campestris* had the highest mean canopy cover of 210m^2/ha and *Sterculia africana* the lowest with 35.8m^2/ha. The mean canopy cover (Mean±SE), t-values and P-values of the tree species found both inside and outside the floodplain are shown in table 3.8. The tree species whose mean canopy covers were higher inside than outside the floodplain were *Acacia nilotica, Acacia robusta* and *Lecaniodiscus fraxinifolius*. The mean canopy covers of all the other tree species were higher outside compared to inside the floodplain. Both inside and outside the floodplain, *Dobera loranthifolius* had the highest mean canopy cover of 146.4±0.0 and 167.9±149.0 respectively. The mean canopy cover of *Prosopis juliflora,* though not among the highest, was significantly higher outside the floodplain compared to inside the floodplain (table 3.8).

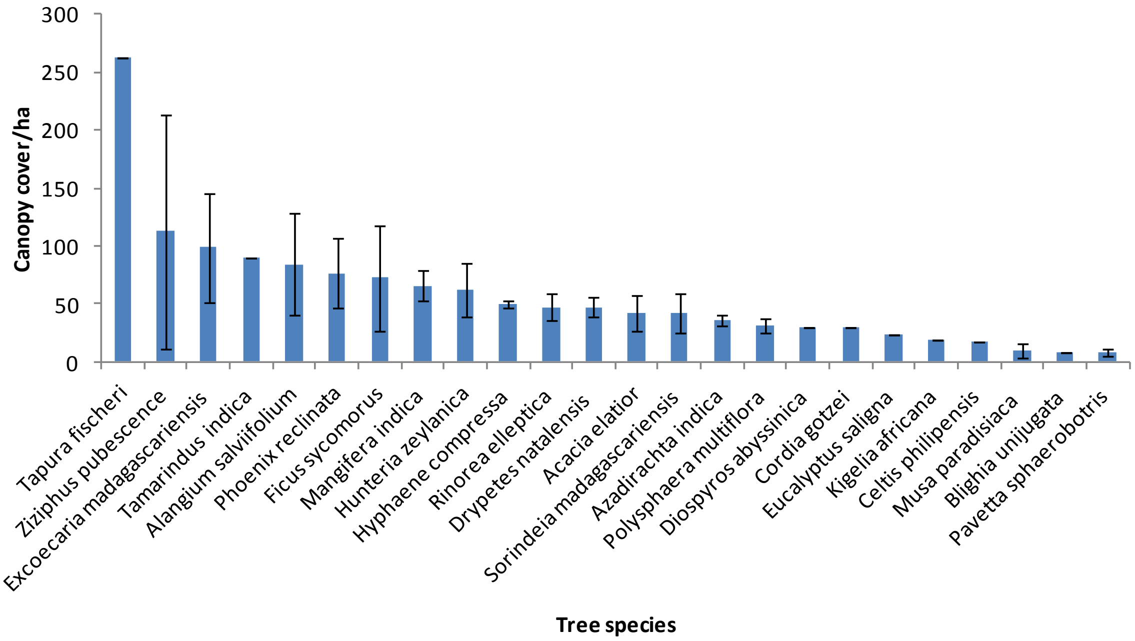

Figure 3.8a: Mean canopy cover and standard errors (Mean±SE) of tree species found inside the floodplain. Standard error bars are missing in cases where the standard error of the species was zero.

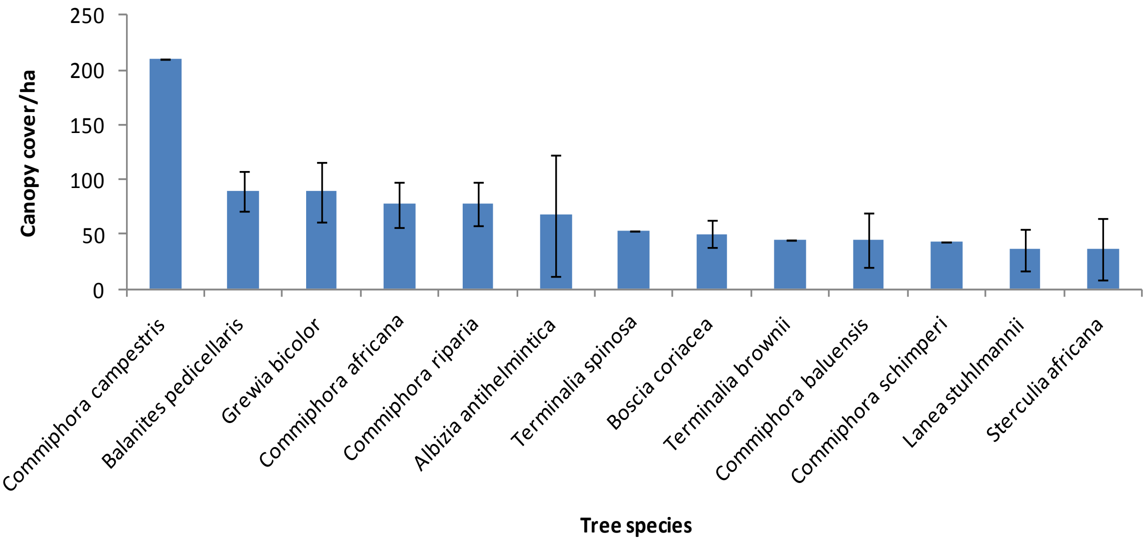

Figure 3.8b: Mean canopy cover and standard errors (Mean±SE) of tree species found outside the floodplain. Standard error bars are missing where the standard error of the species was zero.

Table 3.8: Comparison of mean canopy cover (Mean±SE) of tree species found both inside and outside the floodplain, ±0 means there was no variation in canopy cover.

Species	In floodplain	Outside floodplain	t-value	P-value
Acacia nilotica	41.0±0.0	23.8±13.2	0.58	0.60
Acacia robusta	85.8±56.9	72.1±14.4	0.18	0.87
Acacia tortilis	30.5±17.0	84.6±20.4	-1.04	0.31
Acacia zanzibarica	19.3±6.8	65.3±27.1	-1.88	0.08
Dobera glabra	57.4±4.3	123.0±38.0	-0.88	0.40
Dobera loranthifolius	146.4±0.0	167.9±149.0	-0.08	0.95
Lecaniodiscus fraxinifolius	69.0±25.6	38.4±0.0	0.40	0.70
Maerua pubescence	22.6±0.0	87.6±22.4	-0.81	0.44
Prosopis juliflora	52.5±7.2	82.9±11.9	-2.10	0.04*
Salvadora persica	41.2±26.0	77.9±17.7	-0.56	0.58
Terminalia parvula	55.1±21.5	152.2±123.1	-0.61	0.51

Key:* = P < 0.05

3.4.1.9 Variation in the importance value of trees

The importance value (IV 200) of the tree species was calculated by the sum total of relative density and relative basal area as shown in section 3.3.1. The relative contribution to IV 200 of trees inside was compared to that outside the floodplain and found to be 98 and 102 respectively. The tree species that occurred inside the floodplain only and outside the floodplain only and their contribution to IV 200 were as shown in figures 3.9a and 3.9b respectively. *Rinorea elleptica* contributed the highest to IV 200 inside the floodplain whereas *Blighia unijugata* contributed the lowest (figure 3.9a). *Commiphora riparia* contributed the highest IV 200 outside the floodplain and the lowest by *Commiphora schimperi* (figure 3.9b). For the tree species found both inside and outside the floodplain (table 3.9), *Prosopis juliflora, Acacia robusta* and *Lecaniodiscus flaxinifolius*, contributed a higher value of IV 200 inside compared to outside the floodplain, with the former having the highest contribution. The contribution to IV 200 of all the other tree species was higher outside compared to inside the floodplain. *Acacia tortilis* had the highest contribution to IV 200 followed by *Salvadora persica* then *Dobera glabra*. *Prosopis juliflora* had the highest overall IV 200, followed by *Acacia tortilis* then *Salvadora persica* (table 3.9).

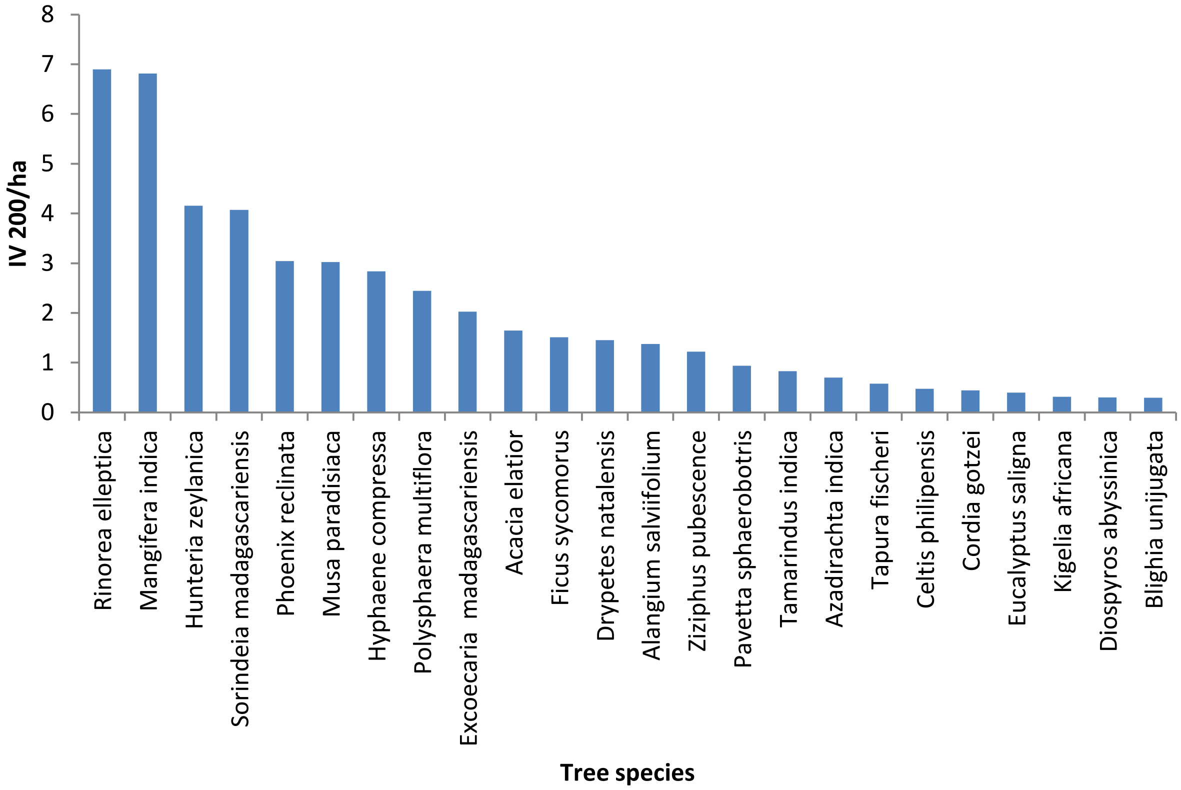

Figure 3.9a: IV 200 of tree species inside the floodplain

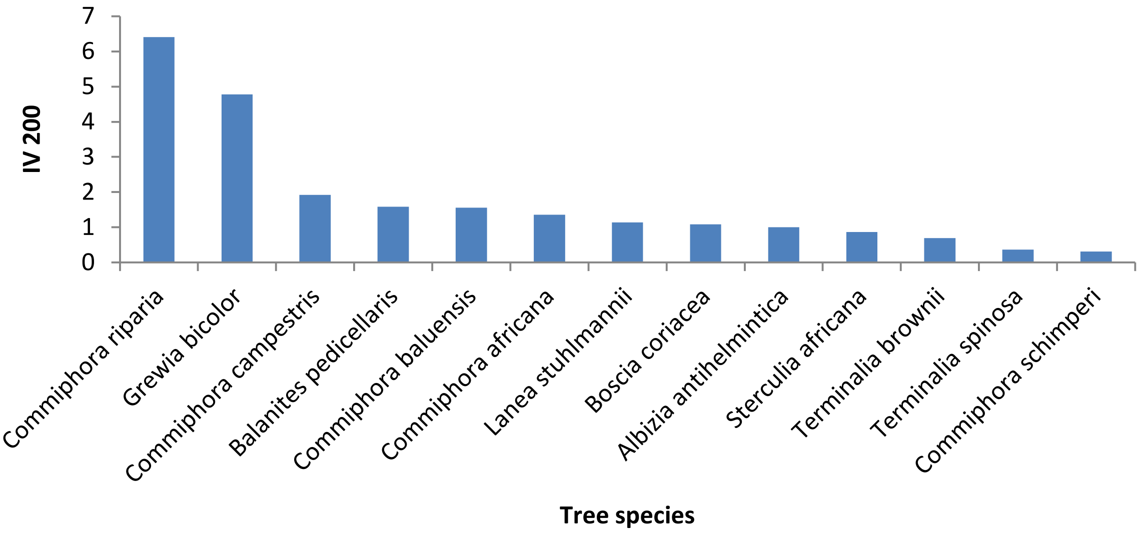

Figure 3.9b: IV 200 of tree species outside the floodplain.

Table 3.9: Comparison of IV 200 of tree species found both inside and outside the floodplain

Tree species	Inside	Outside	Total IV
Acacia tortilis	1.6	19.6	21.2
Acacia nilotica	0.5	1.4	1.9
Acacia robusta	2.1	0.9	3.0
Acacia zanzibarica	2.8	3.2	6.0
Dobera glabra	1.6	10.9	12.5
Dobera loranthifolius	0.6	2.1	2.7
L. fraxinifolius	5.6	0.4	6.0
Maerua pubescence	0.3	7.6	7.9
Prosopis juliflora	33.2	13.5	46.7
Salvadora persica	1.1	15.9	17.0
Terminalia parvula	1.1	3.0	4.1

3.4.2 Vegetation abundance and richness among land use types

Sampling in the three land use types was done in a total of 19, 22 and 21 transects in wildlife conservation, livestock grazing and irrigated agricultural areas respectively. Most of the data on irrigated agriculture was collected inside the floodplain where agriculture is mainly practiced and the rest was collected in Bura and Hola Irrigation Schemes. In Tana River and Arawale National Reserves (conservation areas), sampling was done in 11 and 8 transects respectively. The transects shown in the species accumulation curves are only those in which new species were found.

3.4.2.1 Variation in tree species richness and density among land use types

Conservation areas were the richest in tree species with 29 tree species in 11 transects (figure 3.10a). However, very few transects in Arawale National Reserve had trees, whereas in Tana River National Reserve all the transects had trees.

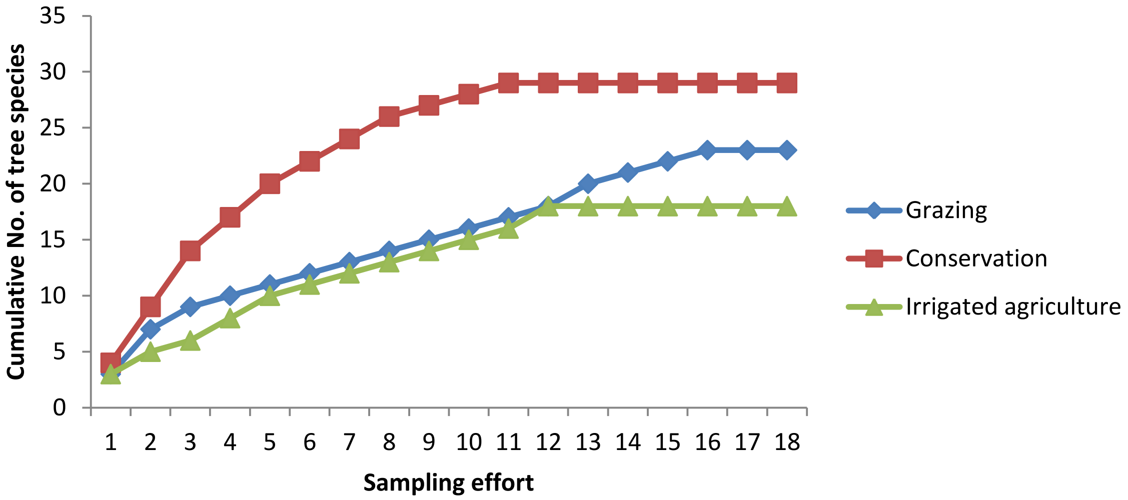

Figure 3.10a: Cumulative number of tree species per land use.

There was no significant difference in tree density (F $_{[2,\ 107]}$ = 0.57, P = 0.57) among the three land use practices. The overall density means were 268±63, 361±64 and 334±70 plants/ha in wildlife conservation, livestock grazing and irrigated agricultural areas respectively. The mean densities of the tree species that were found in conservation, grazing and irrigated agriculture areas were as shown in figures 3.10b, 3.10c and 3.10d respectively. In wildlife conservation areas, the density ranged between 850±650 plants/ha represented by *Rinorea elleptica* to 100±0 represented by five tree species (figure 3.10b). The standard error mean of all the tree species in livestock grazing areas was zero and the mean densities ranged between 100±0 and 200±0 plants/ha. The highest and the lowest mean densities in grazing areas were each represented by four tree species (figure 3.10c). In irrigated agricultural areas, the highest density was represented by the fruit trees (*Mangifera indica* and *Musa paradisiaca),* with *Mangifera indica* having more variations. The lowest mean density in irrigated agricultural areas was represented by three tree species (figure 3.10d).

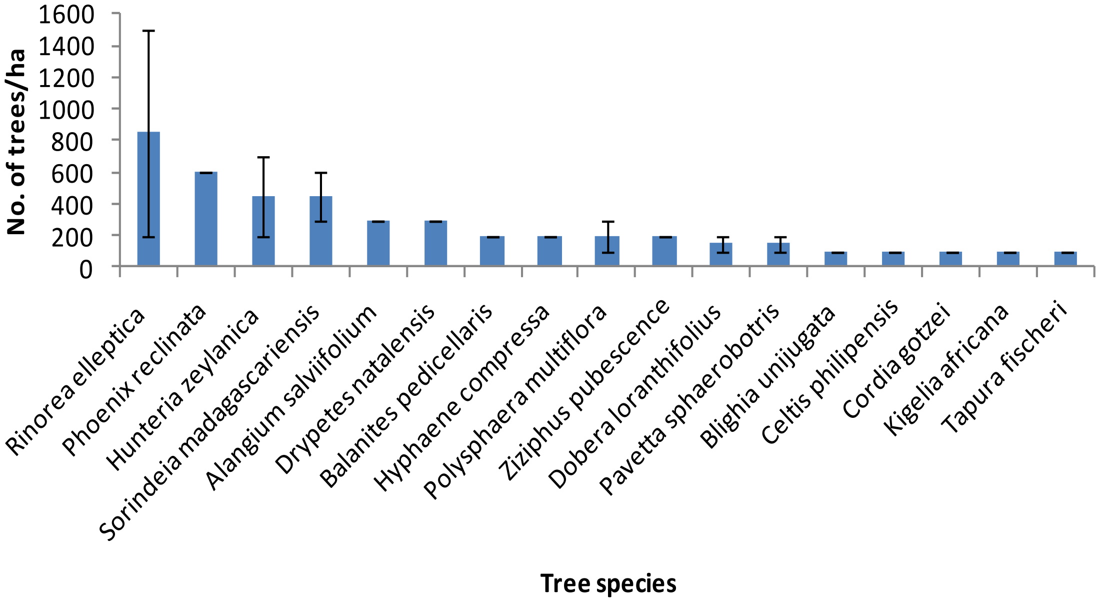

Figure 3.10b: Mean densities (Mean± SE) of tree species found only in wildlife conservation areas. Standard error bars are missing where the standard error of the species was zero.

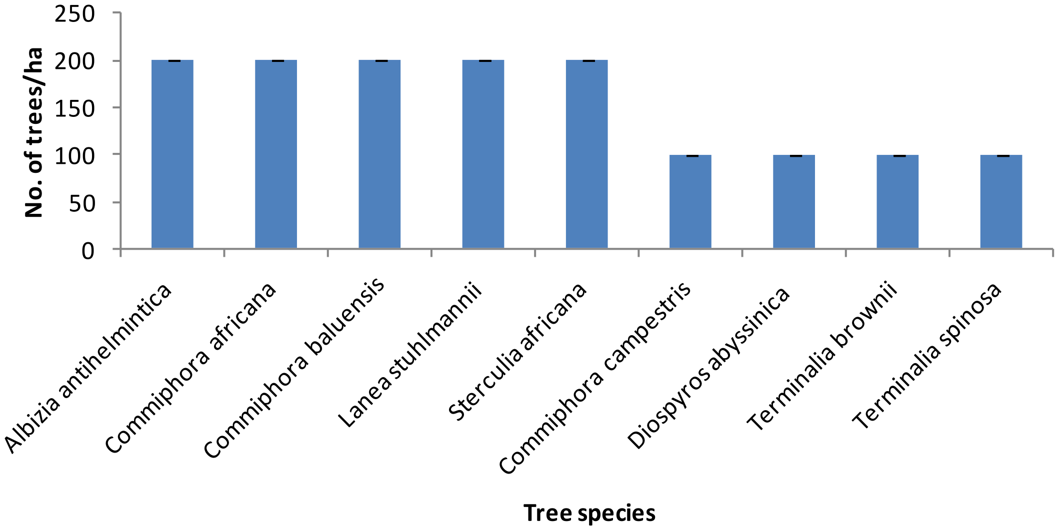

Figure 3.10c: Mean densities (Mean± SE) of tree species found only in livestock grazing areas. The standard error was zero for all the species thus no error bars.

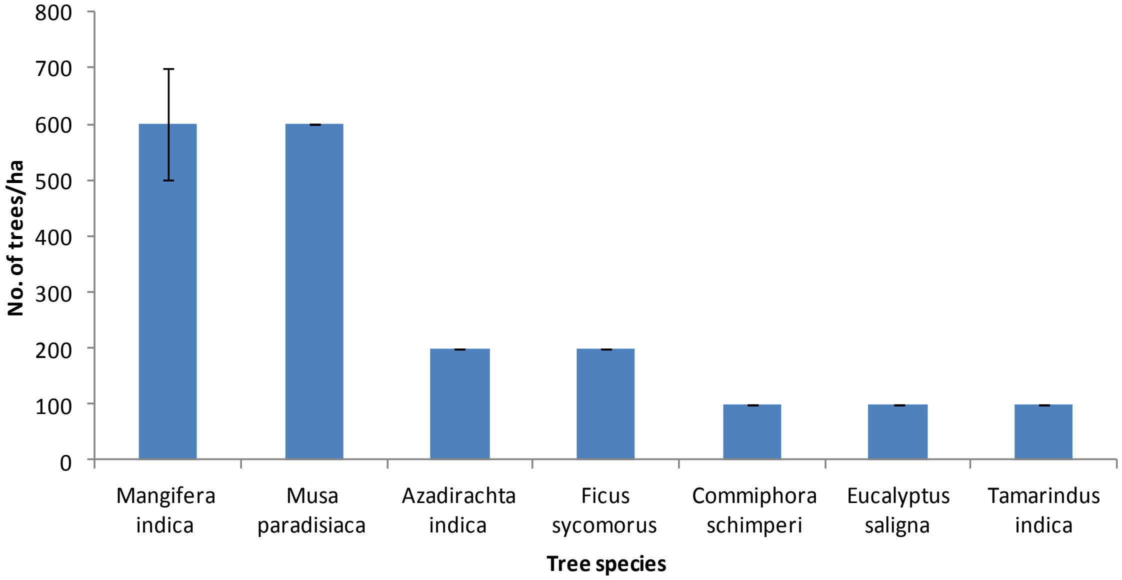

Figure 3.10d: Mean densities (Mean±SE) of tree species found only in irrigated agricultural areas. The stardard error was zero for all the species except *Mangifera indica.*

Among the trees found in two or all the three land use areas (table 3.10), *Salvadora persica, Acacia tortilis*, *Dobera glabra* and *Terminalia parvula* had the highest mean densities in grazing areas compared to other land use areas. *Maerua pubescence* had the highest mean density in conservation areas compared to its density in the other land use areas. *Prosopis juliflora* had the highest mean density compared to the other species, but its density was highest in irrigated agricultural areas compared to other land uses. There was however no significant difference between the densities of any of the tree species among the land uses.

Table 3.10: ANOVA comparison of mean densities (Mean±SE) of tree species in more than one land use type, ±0 means there was no variation in density.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia elatior	0	150±50	100±70	0.33	0.67
Acacia nilotica	0	400±0	100±0	-	-
Acacia robusta	100±0	100±0	200±0	-	-
Acacia tortilis	200±545	575±272	200±385	0.41	0.69
Acacia zanzibarica	0	300±33	267±27	0.60	0.50
Boscia coriacea	100±0	0	100±0	-	-
Commiphora riparia	0	350±150	200±212	0.33	0.67
Dobera glabra	150±72	333±59	100±103	2.92	0.20
E. madagascariensis	0	100±0	100±0	-	-
Grewia bicolor	100±0	200±0	100±0	-	-
L. fraxinifolius	233±109	0	100±133	0.60	0.50
Maerua pubescence	400±176	150±176	100±176	0.84	0.51
Prosopis juliflora	600±885	975±442	1275±442	0.27	0.77
Salvadora persica	250±267	633±218	200±267	1.01	0.44
Terminalia parvula	100±0	200±0	100±0	-	-

Key: *E.* is *Excoecaria*, *L.* is *Lecaniodiscus*, Conserv. is conservation and Irr. Agric is irrigated agriculture. 0 means assessed and found to be zero.

3.4.2.2 Variation in shrub species richness and density among land use types

Grazing areas were the richest in shrub species, followed closely by conservation areas with 34 and 33 shrub species found in 20 and 15 transects respectively (figure 3.11a). Like the tree species, areas where irrigated agriculture was practiced were shrub species poor.

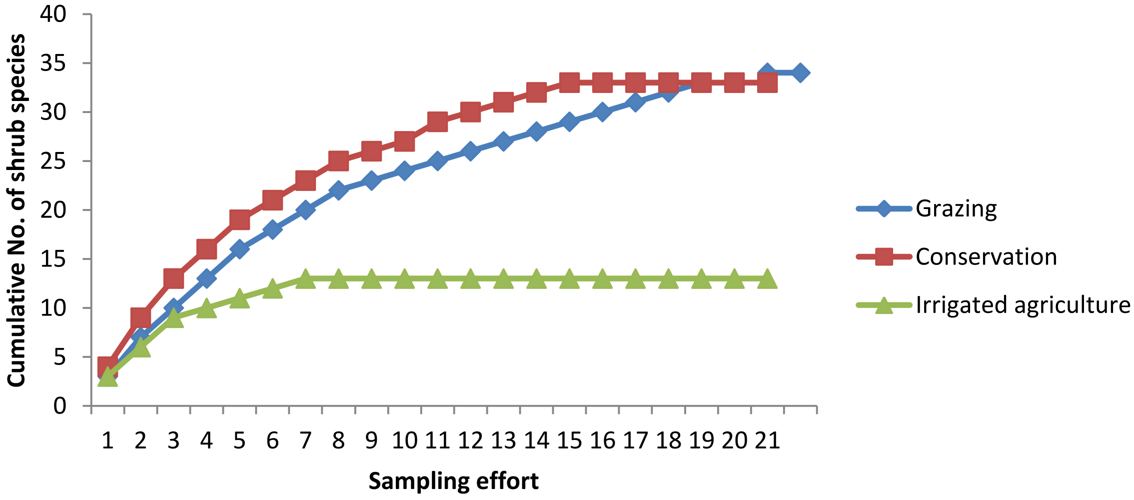

Figure 3.11a: Cumulative number of shrub species per land use.

The overall density means were 1086±173, 1467±170 and 1320±270 in conservation, grazing and irrigated agricultural areas respectively. There was thus no significant difference in the density of shrub species among the three land use practices ($F_{[2,117]} = 1.24$, $P = 0.29$). The shrub species that were found in conservation and grazing areas were as shown in figures 3.11b and 3.11c respectively. A*butilon mauritianum* was the only shrub found only in irrigated agricultural areas. The range of shrub density in conservation areas was from 2000±0 plants/ha represented by *Chrytranthus obliquinervis* to 400±0 plants/ha represented by nine shrub species (figure 3.11b). The density of *Indigofera lupatana* varied the most in conservation areas. In grazing areas, the highest mean density was 2600±600 plants/ha represented by *Thylachium thomasii* and the lowest was 400±0 plants/ha represented by ten shrub species (figure 3.11c).

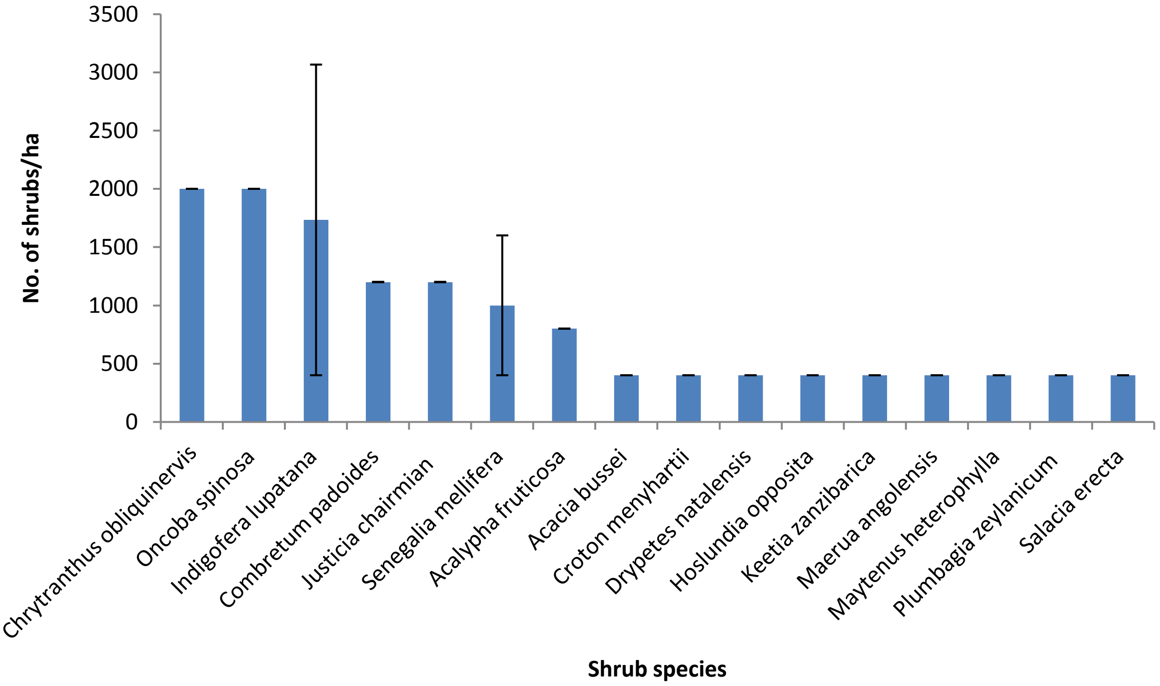

Figure 3.11b: Mean densities and standard errors (Mean±SE) of shrub species found only in conservation areas. Standard error bars are missing where the standard error of the species was zero.

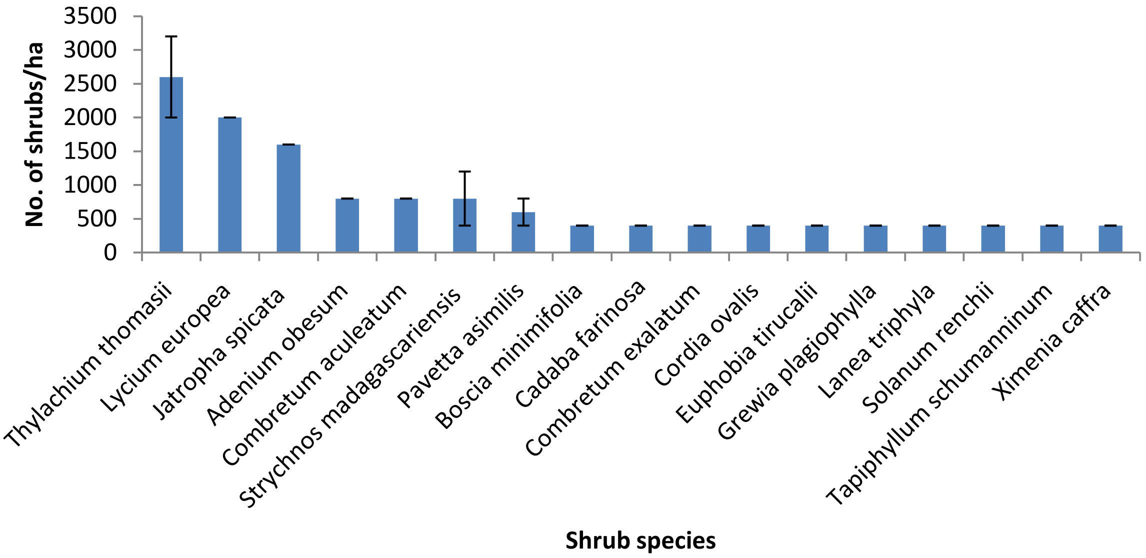

Figure 3.11c: Mean densities and standard errors (Mean±SE) of shrub species found only in livestock grazing areas. Standard error bars are missing where the standard error of the species was zero.

The shrub species that were found in two or all the three land use areas, their mean densities and standard errors, F- values and the significant levels at 0.05 are shown in table 3.11. The shrub species whose densities were higher in conservation areas than in the other land use areas were *Acacia reficiens*, *Cadaba mirabilis*, *Cordia sinensis* and *Harizonia abyssinica,* with the former having the highest density. There were more shrub species whose mean densities were higher in grazing areas than in the other land uses. These were *Barleria taitensis* whose mean density was the highest, *Grewia tembensis*, *Tenantia senii, Sericocomopsis hilderbrandtii, Salsola dendroides, Phyllanthus sepialis, Grewia villosa, Grewia tenax* and *Combretum hereroense*. The densities of *Barleria taitensis* and *Grewia tembensis* were significantly higher in grazing areas compared to their densities in conservation areas. Only *Phyllanthus ovalifolius* and *Thespesia danis* had their mean densities higher in irrigated agricultural areas compared to other land use areas.

Table 3.11: ANOVA comparison of mean densities (Mean±SE) of shrub species in more than one land use type, ±0 means there was no variation in density. High t-values but not significant P-values implies the variance in density was very high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia reficiens	2600±702	2400±702	1600±702	0.57	0.62
Barleria taitensis	600±141	5600±141	0	625.00	0.00**
Cadaba mirabilis	2400±0	800±0	400±0	-	-
Combretum hereroense	800±0	1400±0	0	3.00	0.33
Cordia sinensis	1200±832	1067±481	533±481	0.41	0.69
Grewia similis	600±200	600±200	0	0.00	1.00
Grewia tembensis	800±327	3200±400	0	21.60	0.02*
Grewia tenax	1400±476	1600±476	400±476	1.82	0.30
Grewia villosa	400±141	1400±141	800±200	12.60	0.07
Harizonia abyssinica	600±0	0	400±0	-	-
Phyllanthus ovalifolius	2400±589	2000±589	4600±721	4.27	0.08
Phyllanthus sepialis	400±849	2200±600	400±849	2.25	0.43
Salsola dendroides	1800±600	4800±849	0	8.33	0.21
S. hilderbrandtii	1000±600	1200±849	800±849	0.06	0.95
Tenantia senii	400±1131	1600±800	0	0.75	0.55
Thespesia danis	2400±1200	0	2800±1697	0.04	0.88

Key: *S.* is *Sericocomopsis*, **= P < 0.01, * = *P* < 0.05

3.4.2.3 Variation in richness and density of woody species saplings among land use types

Grazing areas were also relatively rich in woody species saplings, with 29 species found in 16 transects. Conservation and irrigated agricultural areas were equally rich in woody species saplings with 25 species each (figure 3.12a).

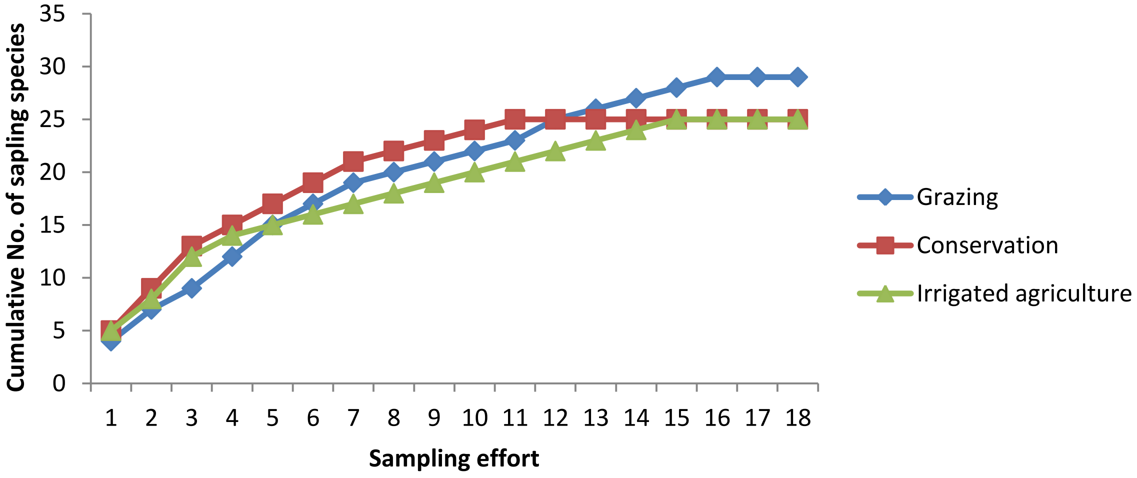

Figure 3.12a: Cumulative number of woody species saplings per land use.

The overall density means of woody saplings were 1497±523, 2009±439 and 2731±492 in conservation, grazing and irrigated agriculture areas respectively. There were no significant differences in the density of saplings ($F_{[2,107]} = 1.51$, $P = 0.23$) among the three land use practices. The range in the mean density of woody species saplings in conservation areas was 3600±0 saplings/ha represented by *Albizia gummifera* to 400±0 saplings/ha represented by five species (figure 3.12b). In grazing areas, the highest density was 2000±800 saplings/ha represented by *Acacia reficiens* and the lowest was 400±0 represented by three species (figure 3.12c). *Ricinus communis* had the highest density of 6400±0 saplings/ha in irrigated agriculture areas whereas the lowest density was represented by four species (figure 3.12d). Among the woody species saplings found in two or all the three land use types (Table 3.12), *Thespesia danis* had the highest density compared to other woody species saplings in conservation areas. The other saplings whose densities were highest in conservation areas than in other land use areas were saplings of *Dobera glabra* and *Oncoba spinosa*. The density of *Dobera glabra* saplings was significantly higher in conservation areas compared to its density in other areas. In grazing areas, *Acacia senegal, Acacia zanzibarica, Grewia villosa* and *Phyllanthus ovalifolius* had densities higher than in the other land use areas. However, the density of *Boscia coriacea* was the highest in grazing areas compared to that of the other species in the same areas, followed by that of *Prosopis juliflora*. The woody species saplings whose densities were highest in irrigated agriculture compared to other land use areas were *Boscia coriacea, Prosopis juliflora, Lecaniodiscus fraxinifolius, Cordia sinensis, Cadaba farinose, Excoecaria madagascariensis* and *Azadirachta indica*. The density of *Boscia coriacea* saplings was also the highest in this land use followed by that of *Prosopis juliflora* whereas *Acacia tortilis had* the least sapling density.

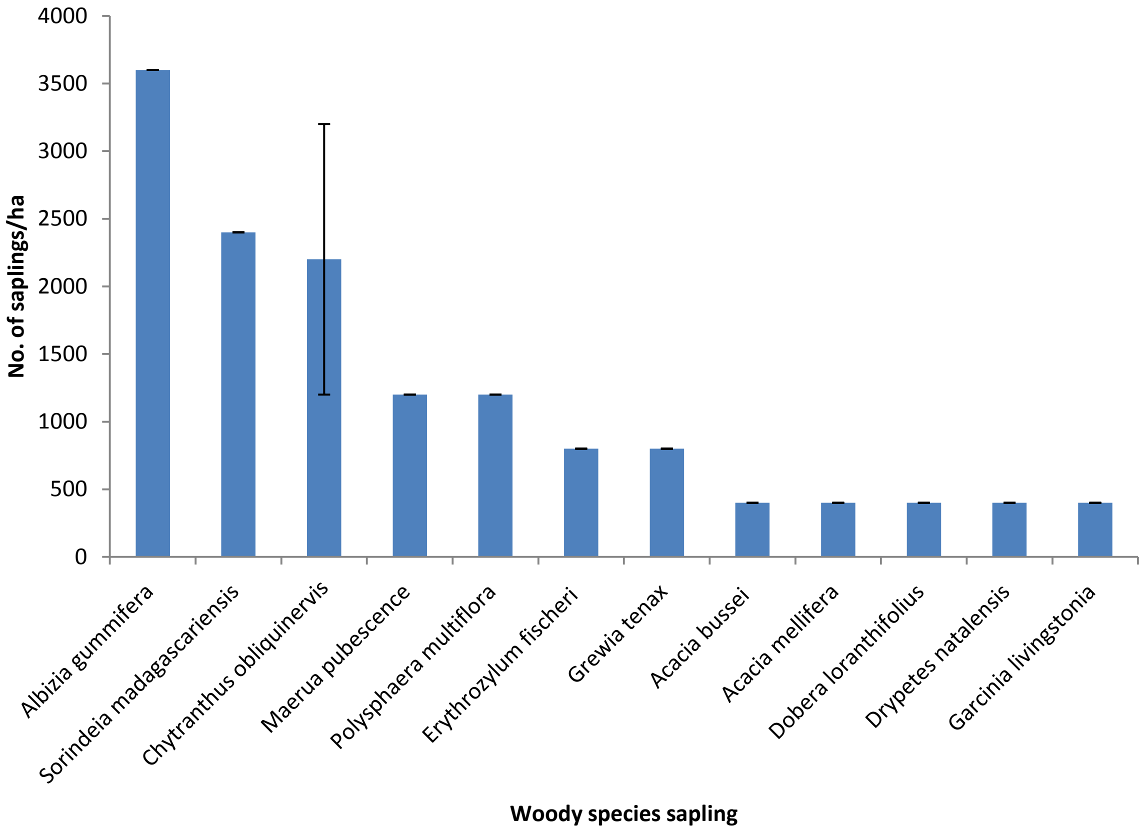

Figure 3.12b: Mean densities and standard errors of woody species saplings found only in conservation areas. No standard error bars means the standard error was zero and thus no variation in density.

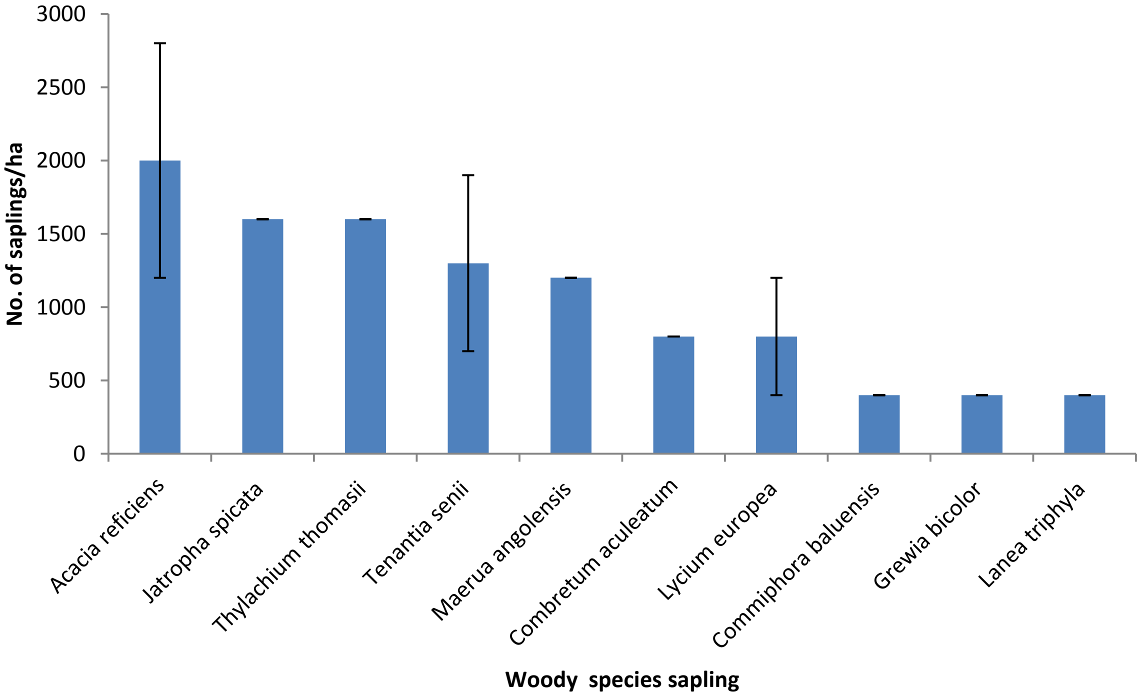

Figure 3.12c: Mean densities of woody species saplings found only in livestock grazing areas. No standard error bars means the standard error was zero and thus no variation in density.

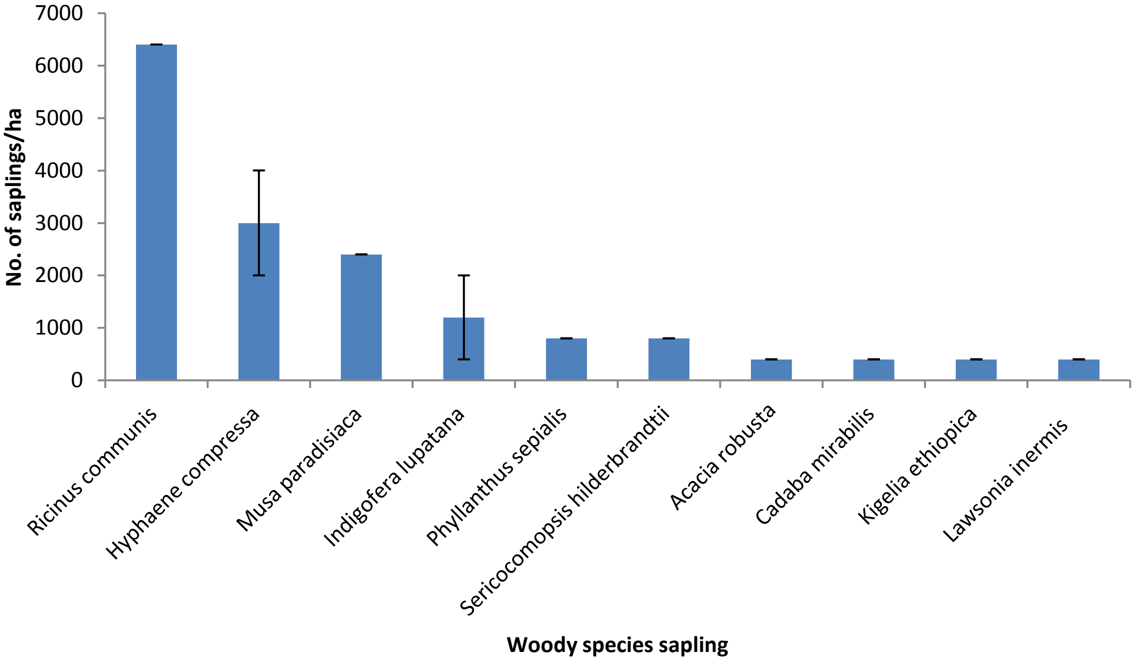

Figure 3.12d: Mean densities of woody species saplings in irrigated agricultural areas. No standard error bars means the standard error was zero and thus no variation in density.

Table 3.12: ANOVA comparison of mean densities (Mean±SE) of woody species saplings in more than one land use type, ±0 means there was no variation in density, 0 means the species was not found in that particular land use type. High t-values and not significant P-values implies the variance was high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia senegal	1200±0	2400±0	0	-	-
Acacia tortilis	400±0	400±0	200±0	-	-
Acacia zanzibarica	400±0	1200±0	400±0	-	-
Acalypha fruticosa	400±0	400±0	0	-	-
Azadirachta indica	0	400±3677	3000±2600	0.333	0.667
Balanites pedicellaris	0	400±0	400±0	-	-
Barleria taitensis	0	400±0	400±0	-	-
Boscia coriacea	1400±2126	8200±2126	15600±3007	7.719	0.115
Cadaba farinosa	0	400±0	800±0	-	-
Cordia sinensis	0	1400±1000	2000±1414	0.120	0.788
Dobera glabra	3200±267	933±217	800±377	24.844	0.014*
E. madagascariensis	0	1600±0	5600±0	-	-
Grewia villosa	1000±600	2000±849	0	0.926	0.512
L. fraxinifolius	400±566	2000±566	2400±400	4.250	0.324
Oncoba spinosa	800±0	400±0	400±0	-	-
Phyllanthus ovalifolius	0	4000±800	3600±1131	0.083	0.821
Prosopis juliflora	2800±5608	6900±2804	8100±2804	0.358	0.713
Salvadora persica	400±267	667±218	0	0.600	0.495
Terminalia parvula	2400±0	400±0	0	-	-
Thespesia danis	4600±1000	800±1414	0	4.813	0.272

Key: *L.* is *Lecaniodiscus*, *E.* is *Excoecaria*, * = $P < 0.05$

3.4.2.4 Variation in density and richness of woody species seedlings among land use types

Conservation areas were richest in woody species seedlings followed by grazing areas with 12 and 9 different species found in 9 and 5 transects respectively. Irrigated agricultural areas had only five different woody species seedling found in three transects only (figure 3.13a).

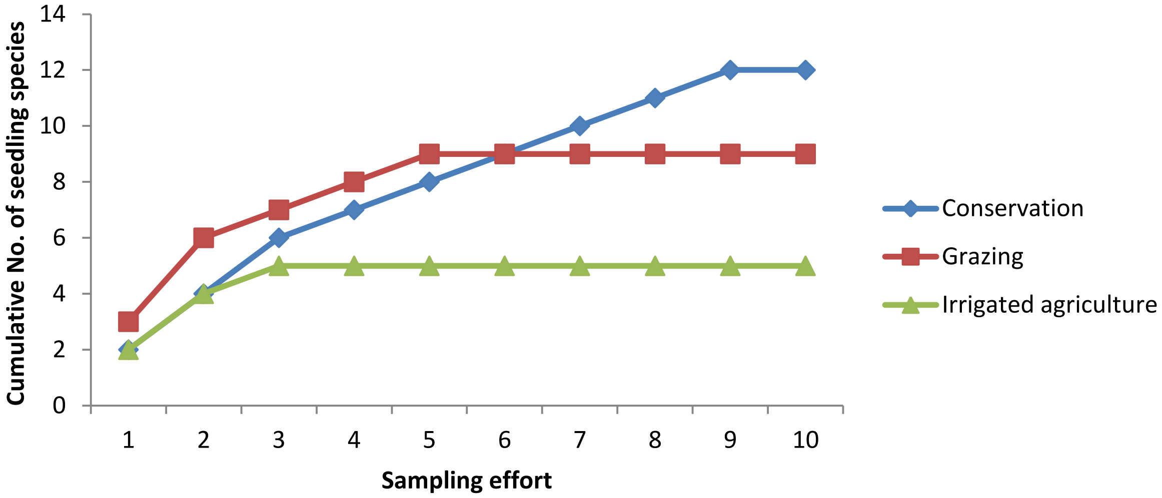

Figure 3.13a: Cumulative number of woody species seedlings per land use.

The overall density means were 11±7, 31±7 and 24±11 per square meter in conservation, grazing and irrigated agricultural areas respectively. There were also no significant differences in the density of seedlings ($F_{[2,49]} = 1.87$, $P = 0.17$) among the land uses. The range in woody species seedling density in conservation areas was 16±4 seedlings/m^2 represented by *Polysphaera multiflora* to 4±0 seedlings/m^2 represented by five species (figure 3.13b). In grazing areas the density of woody species seedlings ranged from12±4 seedlings/m^2 to 4±0 seedlings/m^2 represented by *Albizia antihelmintica* and *Commiphora baluensis* respectively (figure 3.13c).

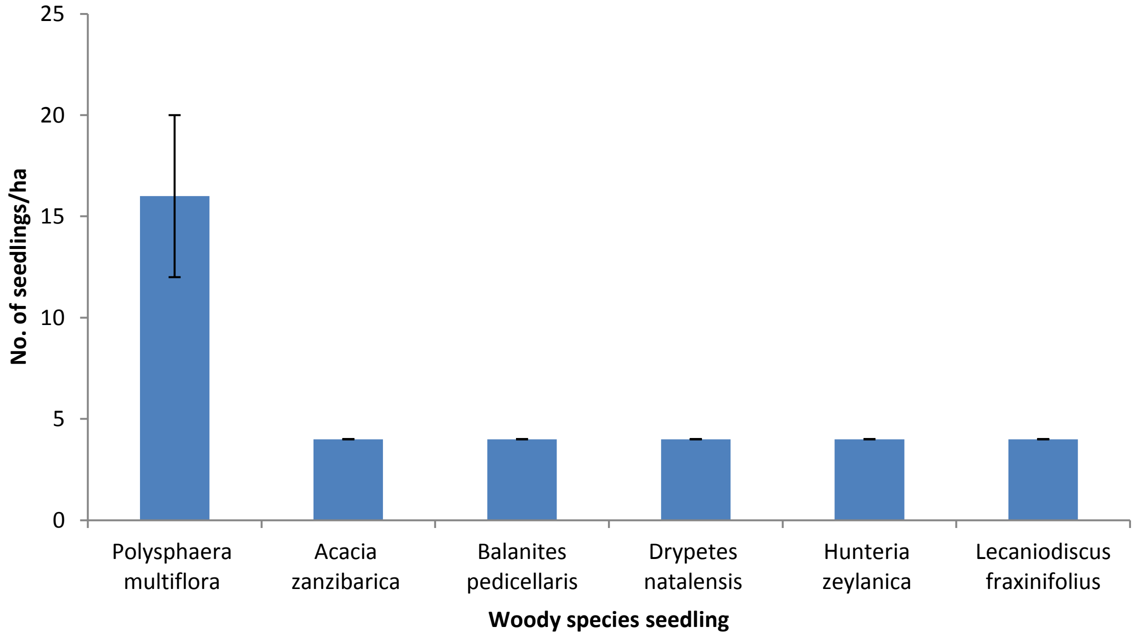

Figure 3.13b: Mean densities and standard errors of woody species seedlings found only in wildlife conservation areas. No standard error bars means the standard error was zero and thus no variation in density.

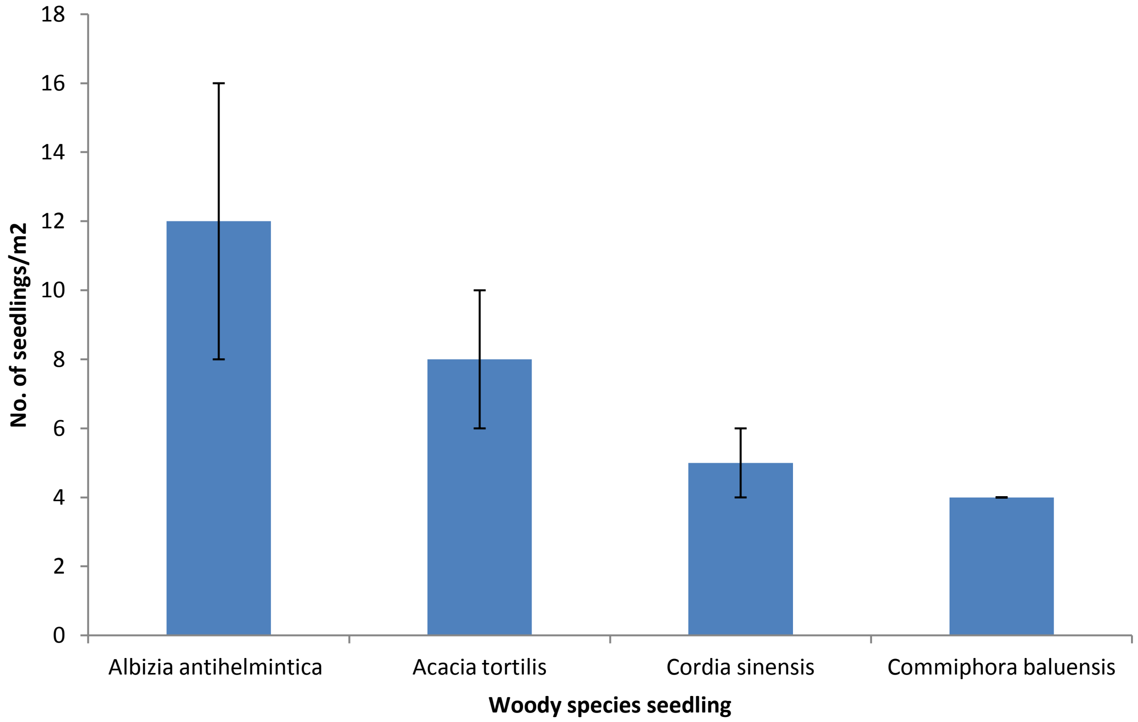

Figure 3.13c: Mean densities and standard errors of woody species seedlings found only in livestock grazing areas. No standard error bars means the standard error was zero and thus no variation in density.

Among the woody species seedlings that were found in two or in all the three land use areas (table 3.13), the mean density of *Sericocomopsis hilderbrandtii* seedlings was highest in conservation areas than in the other land use areas. In the grazing areas, the densities of *Acacia reficiens* and *Acacia elatior* were highest compared to their densities in the other land use areas, the density of the latter being the highest compared to that of the other seedlings. The density of *Acacia elatior* seedlings was also significantly higher in grazing areas compared to its density in conservation areas. *Prosopis juliflora* and *Boscia coriacea* had their highest densities in irrigated agriculture areas compared to the other land use areas, with the former having the highest density.

Table 3.13: ANOVA comparison of mean densities/m^2 (Mean±SE) of woody species seedlings in more than one land use type, ±0 means there was no variation in density.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia elatior	4±6	145±5	0	354.80	0.00**
Acacia mellifera	8±2	8±4	0	0.00	1.00
Acacia reficiens	24±17	46±17	8±23	0.97	0.51
Boscia coriacea	4±0	*0*	8±0	-	-
Phyllanthus ovalifolius	0	4±0	4±0	-	-
Prosopis juliflora	11±8	13±11	42±8	3.13	0.05*
S. hilderbrandtii	52±0	0	12±0	-	-

Key: *S.* is *Sericocomopsis,* ** = P < 0.01, * P = 0.05

3.4.2.5 Variation in richness and density of forb species among land use types

Forb species richness was 22, 20 and 18 found in 11, 7 and 9 transects in livestock grazing, wildlife conservation and irrigated agricultural areas respectively (figure 3.14a).

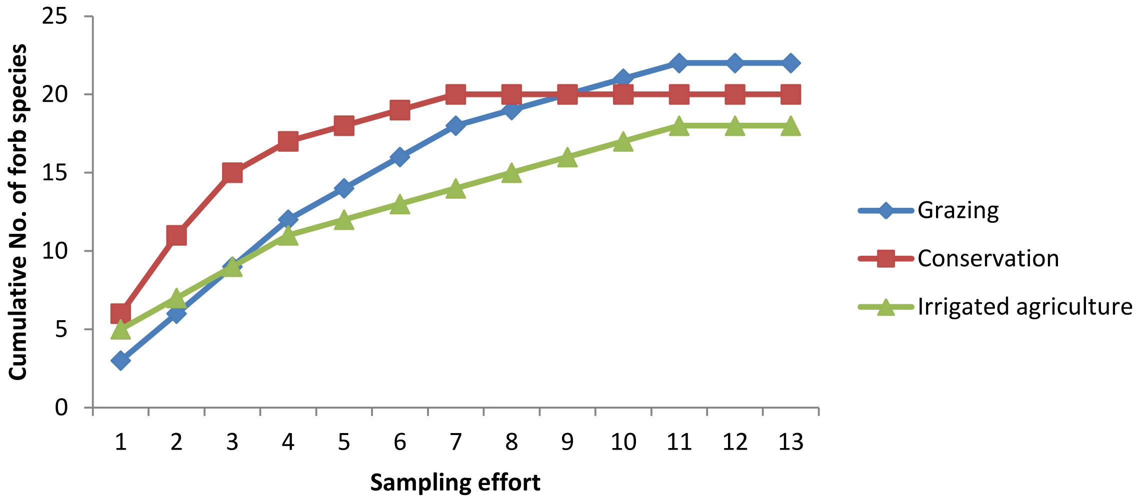

Figure 3.14a: Cumulative number of forb species per land use

The difference in the density of forbs was not significant among the land uses ($F_{[2, 105]} = 1.71$, $P = 0.19$), with overall density means of 8±2, 9±2 and 13±2 plants/m^2 in conservation, grazing and irrigated agriculture areas respectively. The range of densities in conservation areas was between 12±0 plants/m^2 represented by *Portulaca quadrifida* to 4±0 plants/m^2 represented by four species (figure 3.14b). The range in grazing areas was between 16±0 plants/m^2 represented by *Sida acuta* to 4±0 plants/m^2 represented by six species (figure 3.14c). In irrigated agriculture areas, *Launea cornuta* had the highest mean density whereas the lowest density was represented by five species (figure 3.14d). Among the forb species found in two or more land uses (table 3.14), *Elvolvulus alsinoides*, *Melhania velutina* and *Ruelia megachlamys* had their highest densities in conservation areas compared to other land use areas. The density of *Ruelia megachlamys* was higher than that of the other species in conservation areas. The densities of *Pupalia lapacea*, *Ruelia patula* and *Hibiscus micranthus* were highest in grazing areas than in the other land use types. However, the density of *Pupalia lapacea* was the highest compared to that of the other species in grazing areas and also significantly higher compared to its density in the other land use types. *Borreria stricta,* *Indigofera schimperi, Justicia declipteroides, Justicia flava* and *commelina benghalensis* had their highest densities in irrigated agriculture areas compared to the other land use areas. The density of *Commelina benghalensis* was not only the highest compared to that of the other forb species but also significantly higher in irrigated agricultural areas compared to its density in the other land use types.

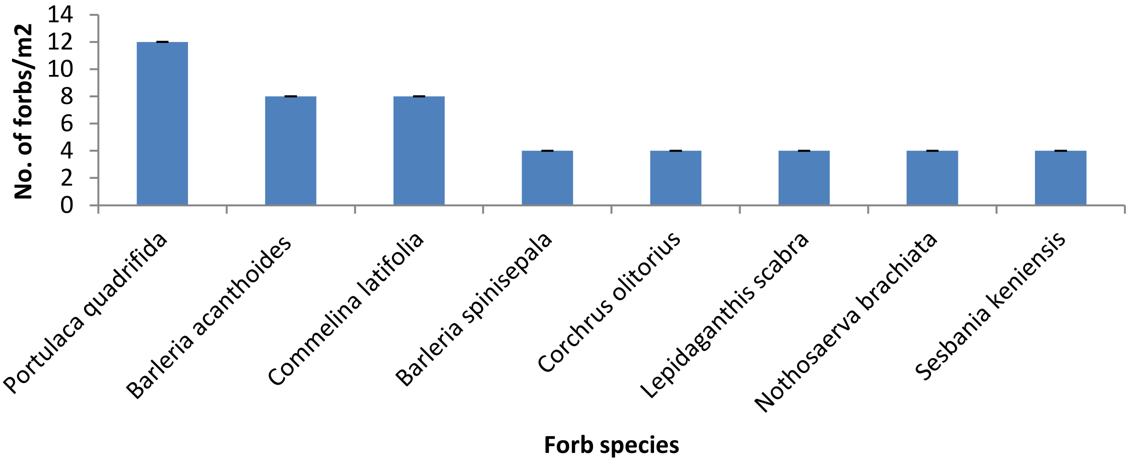

Figure 3.14b: Mean densities and standard errors of forb species found only in wildlife conservation areas. No standard error bars means there was no variation in density.

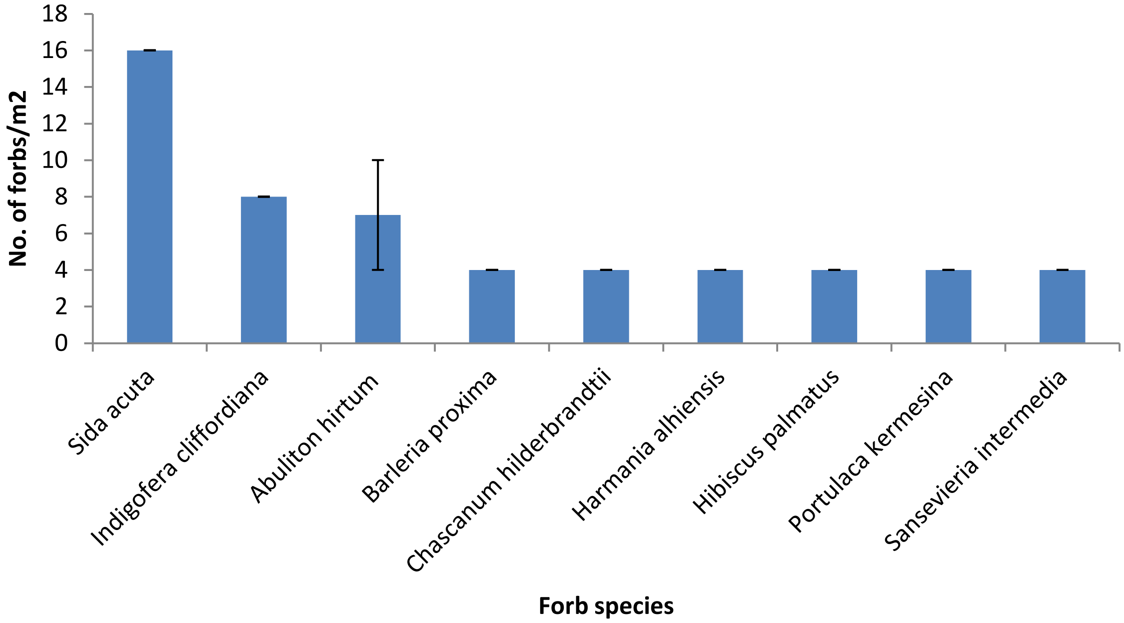

Figure 3.14c: Mean densities and standard errors of forb species found only in livestock grazing areas. No standard error bars means there was no variation in density.

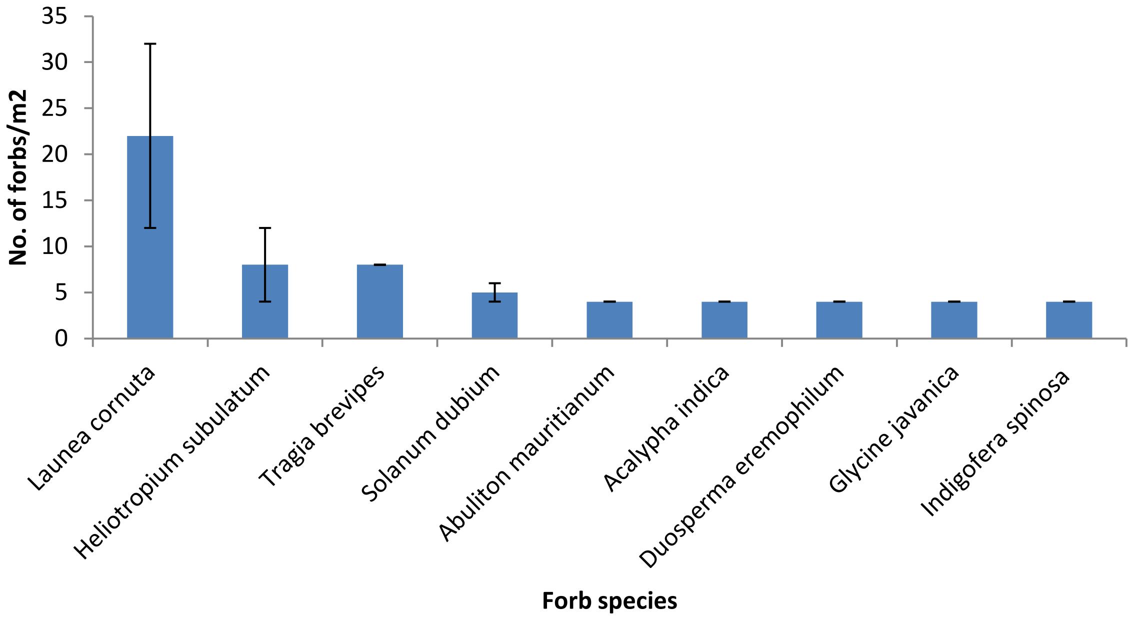

Figure 3.14d: Mean densities and standard errors of forb species found only in irrigated agricultural areas. No standard error bars means there was no variation in density

Table 3.14: ANOVA comparison of mean densities (Mean±SE) of forbs in more than one land use type, ±0 means there was no variation in density, high t-values and not significant P-values means the variance was high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Aerva lanata	4±0	4±0	0	-	-
Borreria stricta	8±0	0	16±0	-	-
Commelina benghalensis	5±1	4±2	52±2	165.80	0.01**
Evolvulus alsinoides	15±4	*6±5*	0	1.51	0.31
Hibiscus micranthus	8±4	14±4	10±4	0.50	0.65
Indigofera schimperi	0	4±6	9±4	0.44	0.54
Justicia declipteroides	7±2	0	12±2	4.00	0.12
Justicia flava	0	7±15	45±13	3.52	0.12
Melhania velutina	8±0	4±0	0	-	-
Ocimum bacilicum	8±2	8±2	0	0.00	1.00
Pavonia patens	4±0	4±0	0	-	-
Pupalia lapacea	13±4	33±4	9±3	14.87	0.00**
Ruelia megachlamys	17±7	0	4±13	0.81	0.46
Ruelia patula	0	16±0	4±0	-	-
Tallinum portulacifolium	4±0	4±0	0	-	-

Key: ** = P ≤ 0.01

3.4.2.6 Variation in richness and density of perennial grass species among land use types

Perennial grass species were 5, 6 and 10 found in 5, 2 and 9 transects in grazing, conservation and irrigated agricultural areas respectively (figure 3.15).

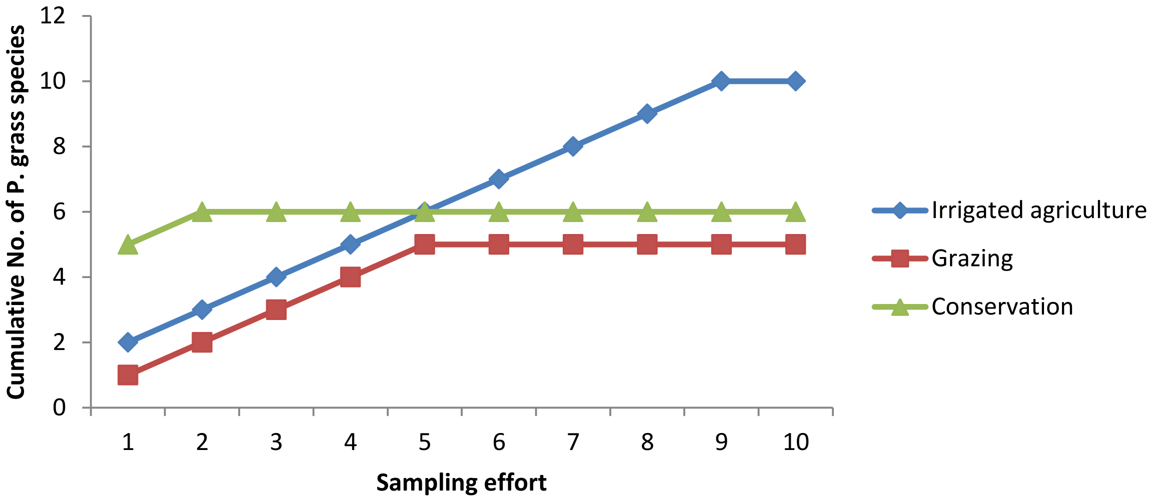

Figure 3.15: Cumulative number of perennial grass species per land use.

There were no significant differences in the density of perennial grasses among the land types ($F_{[2,\,57]} = 0.53$, $P = 0.59$), the overall mean densities being 23±9, 36±9 and 32±8 plants/m^2 in conservation, grazing and irrigated agriculture areas respectively. Except for *Eraglostis superba* and *Latipes senegalensis* which were found only in irrigated agriculture areas with mean densities of 10±6 and 6±2 plants/m^2 respectively, the other perennial grasses were found in two or all the three land use types. Among those found in two or all the three land use types (table 3.15), only *Chloris roxburghiana* had its highest mean density in conservation areas. *Enteropogon macrostachyus* and *Tetrapogon bidentatus* had their highest densities in grazing areas. *Cynodon dactylon*, *Echinochloa pyramidalis* and *Sporobolus helvolus* had their highest densities in irrigated agriculture areas, with the former having the highest density. In all the land use areas however, the density of *Cynodon dactylon* was higher than that of the other perennial grasses.

Table 3.15: ANOVA comparison of mean densities (Mean±SE) of perennial grasses in more than one land use type, ±0 means there was no variation in density. High t-values and not significant P-values means the variance was high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Cenchrus ciliaris	4±0	0	4±0	-	-
Chloris roxburghiana	10±2	0	8±4	3.00	0.33
Cynodon dactylon	47±20	62±19	95±20	1.49	0.26
Echinochloa pyramidalis	6±4	8±0	14±3	1.39	0.33
Enteropogon macrostachyus	19±12	34±10	11±11	1.17	0.37
Panicum maximum	0	4±0	4±0	-	-
Sporobolus helvolus	10±1	0	16±1	9.00	0.10
Tetrapogon bidentatus	13±6	17±6	4±11	0.54	0.62

3.4.2.7 Variation in tree basal area among land use types

The overall basal area means of trees were 9.5±1.3, 8.5±1.2 and 10.3±1.3m^2/ha in conservation, grazing and irrigated agriculture areas respectively. The difference in the basal area of trees was not significant ($F_{[2, 348]} = 0.49$, $P = 0.62$) among the three land use practices. In conservation areas (figure 3.16a), the range in basal area of tree species was 19.5±13.4m^2/ha to 0.3±0m^2/ha, the highest represented by *Dobera loranthifolius* and the lowest by *Blighia unijugata*. The range in grazing areas was 53.9m^2/ha to 0.5m^2/ha represented by *Commiphora campestris* and *Diospyros abyssinica* respectively (figure 3.16b). *Tamarindus indica* had the highest mean basal area in irrigated agriculture areas followed closely by *Ficus sycomorus,* with *Commiphora schimperi* having the lowest basal area. Among the species found in two or all the three land use areas (table 3.16), the basal area of *Acacia tortilis* was the highest in irrigated agriculture areas compared to its basal area in other land use areas and also compared to other tree species. Its mean basal area and that of *Salvadora persica* were also significantly higher in irrigated agriculture compared to other land use areas. In conservation areas, the tree species with the highest mean basal area was *Dobera glabra* whereas in grazing areas *Terminalia parvula* had the highest mean basal area. Although the mean basal area of *Prosopis juliflora* was relatively low compared with that of other tree species, it was highest in conservation areas compared to other land use types.

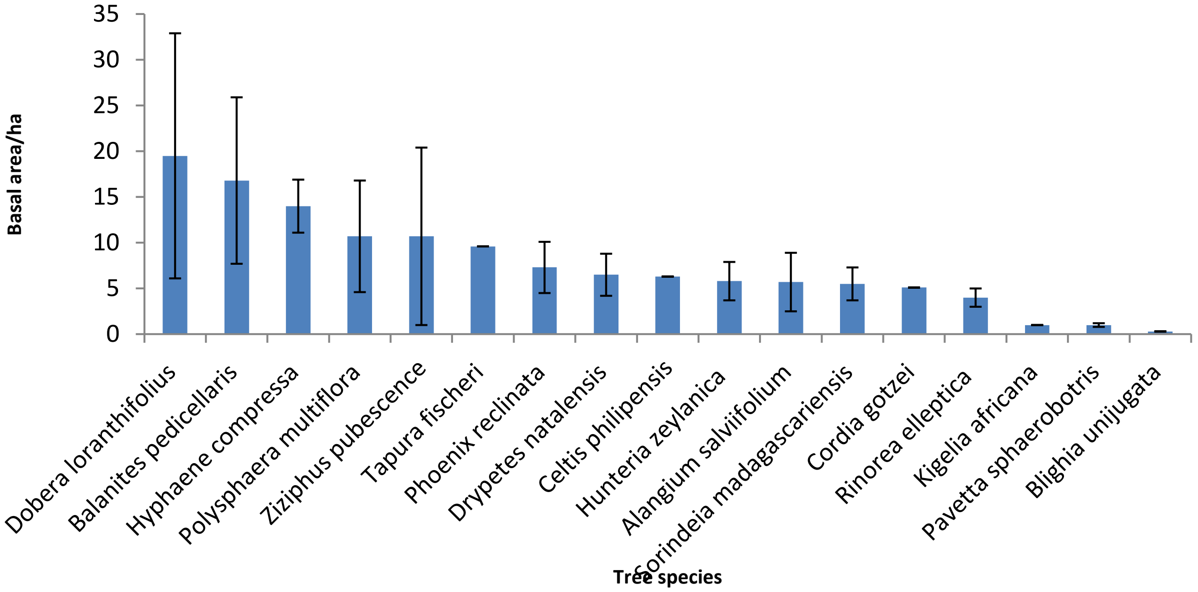

Figure 3.16a: Mean basal areas and standard errors of tree species found only in wildlife conservation areas. No standard error bars means there was no variation in basal area.

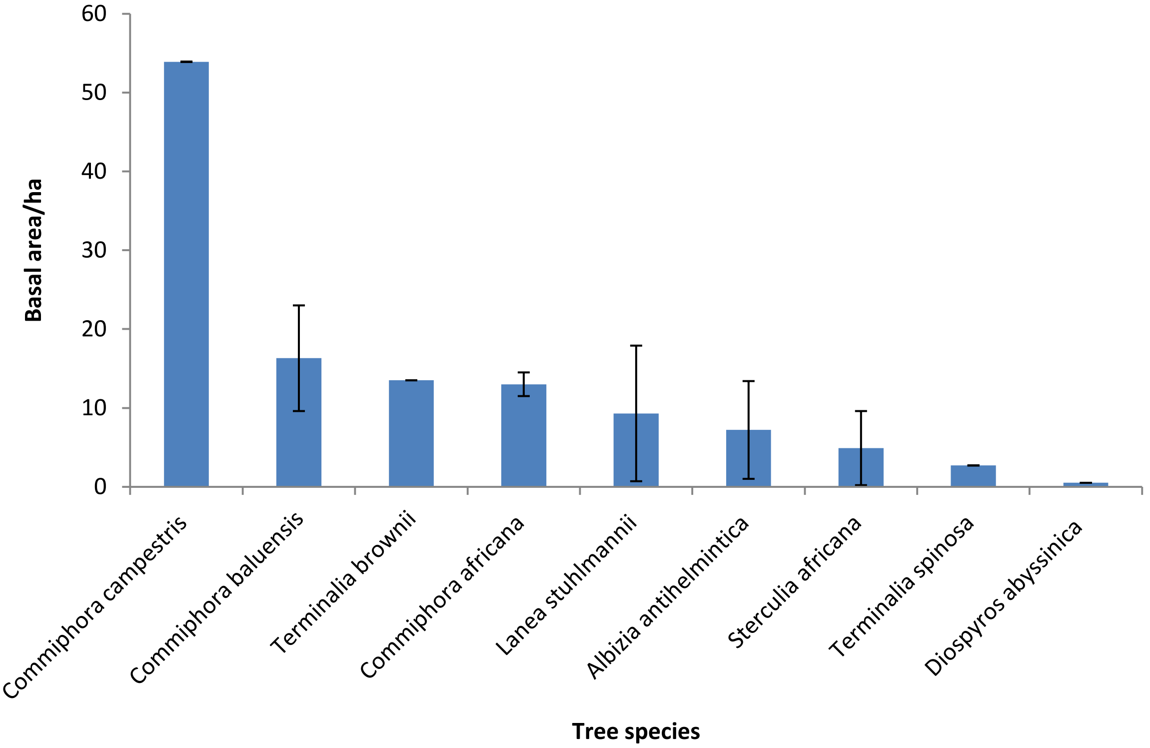

Figure 3.16b: Mean basal areas and standard errors of tree species found only in livestock grazing areas. No standard error bars means there was no variation in basal area.

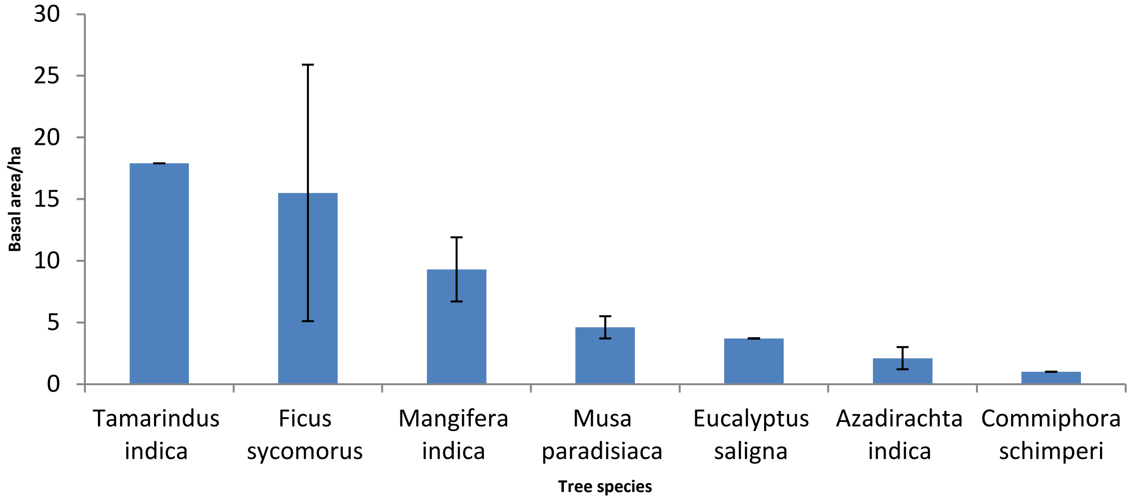

Figure 3.16c: Mean basal areas of tree species found only in irrigated agricultural areas. No standard error bars means there was no variation in basal area.

Table 3.16: ANOVA comparison of basal area (Mean±SE) of tree species in more than one land use type, ±0 means there was no variation in basal area. High t-values but not significant P-values means the variance was high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia elatior	0	4.4±1.0	3.7±1.7	0.12	0.77
Acacia nilotica	0	2.1±1.1	6.0±2.1	2.69	0.20
Acacia robusta	1.8±18.7	5.4±13.2	19.9±13.2	0.44	0.70
Acacia tortilis	7.5±4.1	7.5±1.7	112.2±15.8	151.94	0.00**
Acacia zanzibarica	0	2.1±2.6	6.7±2.2	1.86	0.20
Boscia coriacea	11.5±0.0	0	5.5±0.0	-	-
Commiphora riparia	0	13.3±6.5	17.9±12.1	0.12	0.74
Dobera glabra	38.5±16.4	15.1±9.0	13.5±28.5	0.81	0.47
E. madagascariensis	0	25.8±4.7	6.4±3.3	11.67	0.18
Grewia bicolor	6.1±16.2	23.0±8.1	2.9±16.2	0.87	0.50
L. fraxinifolius	15.0±6.4	0	3.8±11.9	0.68	0.44
Maerua pubescence	14.8±4.1	6.3±6.6	1.4±8.1	1.41	0.29
Prosopis juliflora	16.0±3.4	5.1±1.3	7.1±1.2	2.61	0.04*
Salvadora persica	12.9±4.3	7.0±2.2	24.4±4.8	5.48	0.01**
Terminalia parvula	2.5±28.8	33.9±20.4	9.3±20.4	0.54	0.65

Key: ** = $P \leq 0.01$, * = $P < 0.05$

3.4.2.8 Variation in tree canopy covers among land use types

There was no significant difference in tree canopy cover ($F_{[2, 348]} = 1.59$, $P = 0.21$) among the three land use practices. The overall canopy cover means were 71.0±6.9, 57.5±6.1 and 72.0±6.9 in conservation, grazing and irrigated agricultural areas respectively. The range in mean canopy cover in conservation areas was 262.4m^2/ha to 7.9m^2/ha represented by *Tapura fischeri* and *Pavetta sphaerobotris* respectively (figure 3.17a). In grazing areas, the mean canopy cover ranged from 210.3m^2/ha to 30.3m^2/ha represented by *Commiphora campestris* and *Diospyros abyssinica* respectively (figure 3.17b). In irrigated agricultural areas the highest mean canopy cover was 90.3m^2/ha and the lowest 23.0m^2/ha represented by *Tamarindus indica* and *Eucalyptus saligna* respectively (figure 3.17c).

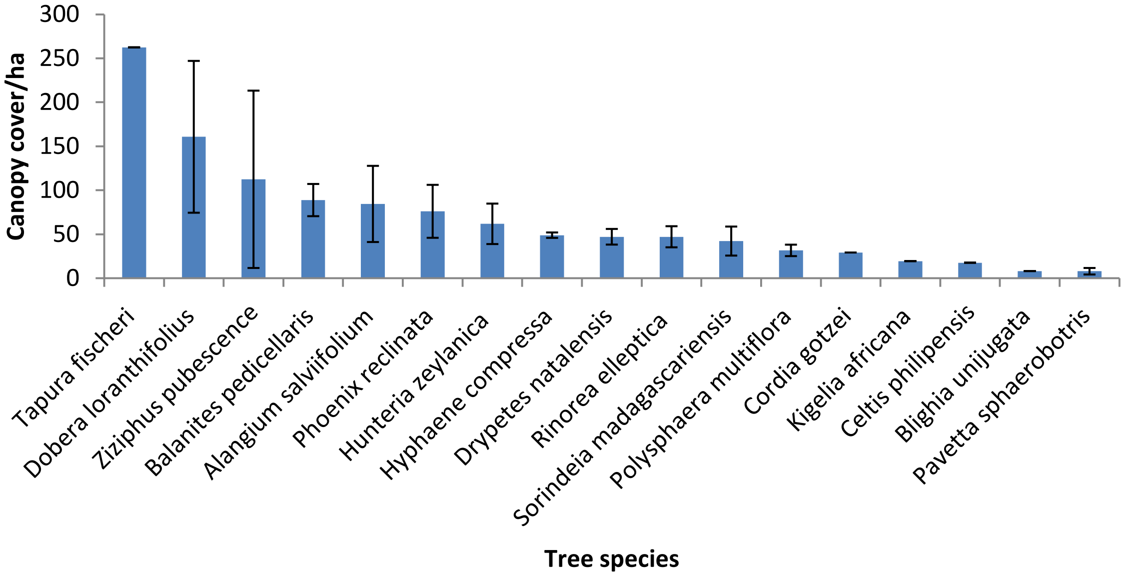

Figure 3.17a: Mean canopy cover and standard error of tree species found only in wildlife conservation areas. No standard error bar means there was no variation in canopy cover.

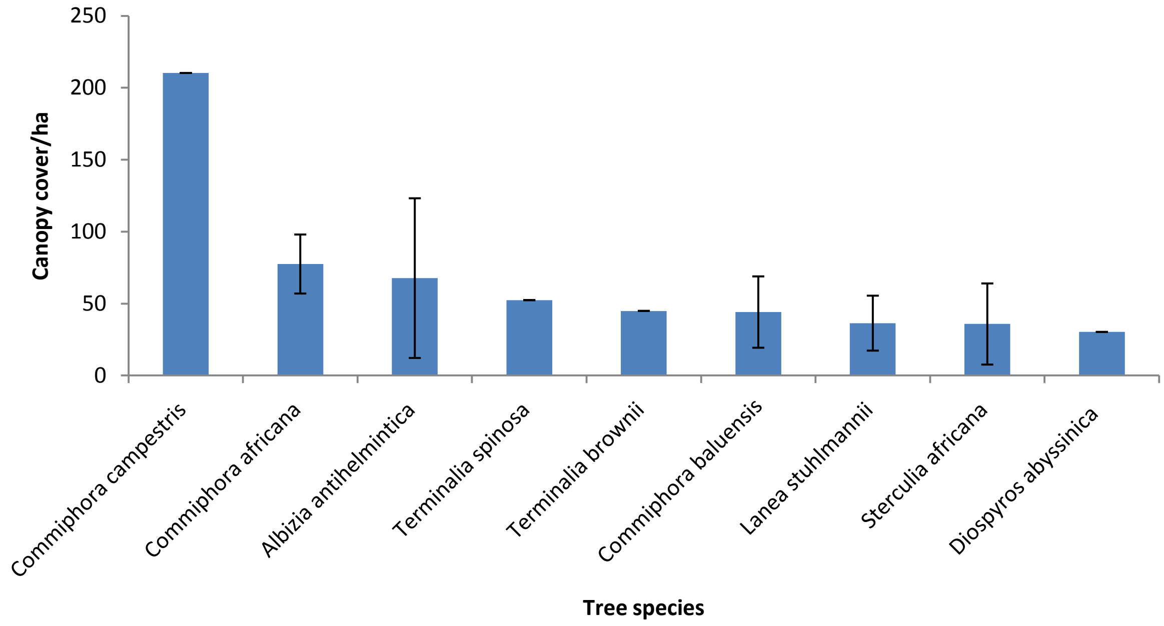

Figure 3.17b: Mean canopy cover and standard errors of tree species found only in livestock grazing areas. No standard error bars means there was no variation in canopy cover.

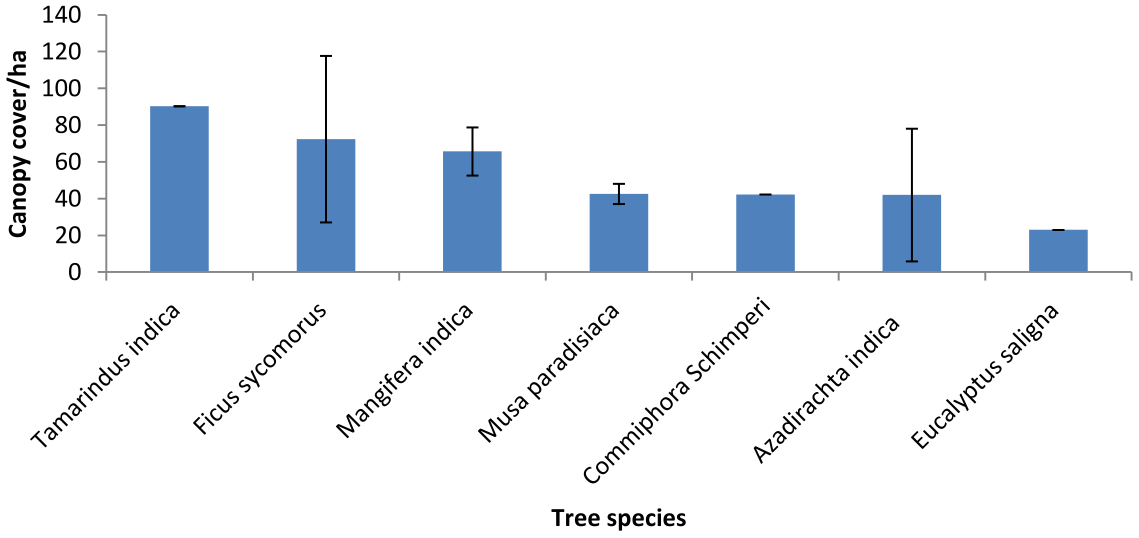

Figure 3.17c: Mean canopy cover and standard errors of tree species found only in irrigated agricultural areas. No standard error bars means there was no variation in canopy cover.

Among the tree species found in two or all the three land use areas (table 3.17), *Dobera glabra* had the highest mean canopy cover compared to other tree species in conservation areas. The canopy cover was also highest in conservation areas compared to its canopy cover in the other land uses. Other tree species whose canopy covers were higher in conservation areas than in other land use areas were *Maerua pubescence, Prosopis juliflora, Boscia coriacea* and *Lecaniodiscus fraxinifolius.* The tree species whose mean canopy covers were highest in livestock grazing areas than in the other land use areas were *Excoecaria madagascariensis, Acacia elatior, Grewia bicolor* and *Terminalia parvula.* The tree species whose mean canopy covers were higher in irrigated agricultural areas than in the other land uses were *Acacia tortilis, Acacia nilotica, Acacia robusta, Acacia zanzibarica, Commiphora riparia* and *Salvadora persica.* The canopy cover of *Acacia tortilis* was highest compared to other species in this area and compared to its cover in other areas. The canopy covers of *Acacia tortilis, Commiphora riparia* and *Salvadora persica* were significant in irrigated agricultural areas than in the other land use types.

Table 3.17: ANOVA comparison of mean canopy cover (Mean±SE) of tree species in more than one land use type, ±0.0 means there was no variation in canopy cover. High t-values but not significant P-values means the variance was high.

Species	Conserv.	Grazing	Irr. Agric	F - ratio	P- value
Acacia elatior	0	51.8±16.9	13.7±29.3	1.27	0.38
Acacia nilotica	0	23.8±13.2	41.0±26.5	0.34	0.60
Acacia robusta	54.7±95.8	72.1±67.8	101.3±67.8	0.09	0.92
Acacia tortilis	55.7±9.7	45.2±23.0	388.0±32.8	48.18	0.00**
Acacia zanzibarica	0	14.3±18.9	57.3±16.3	2.94	0.11
Boscia coriacea	62.4±0.0	0	38.4±0.0	-	-
Commiphora riparia	0	57.3±18.3	147.4±34.2	5.41	0.05*
Dobera glabra	165.7±68.5	97.9±37.5	49.7±118.6	0.51	0.61
E. madagascariensis	0	189.1±33.2	53.1±23.5	11.18	0.19
Grewia bicolor	46.2±69.8	112.6±34.9	35.2±69.8	0.71	0.56
L. fraxinifolius	75.2±26.6	0	32.2±49.7	0.58	0.47
Maerua pubescence	111.9±25.4	40.7±41.5	27.5±50.9	1.76	0.22
Prosopis juliflora	84.2±24.9	45.9±9.8	67.4±8.6	1.88	0.16
Salvadora persica	130.7±35.6	46.7±18.3	141.7±39.9	3.82	0.04*
Terminalia parvula	17.6±179.8	219.5±127.1	55.1±127.1	0.60	0.63

Key: ** = $P < 0.01$, * = $P \leq 0.05$

3.4.2.9 Variation in tree importance value among land use types

The overall relative contribution to IV 200 of the tree species in wildlife conservation, livestock grazing and irrigated agricultural areas was 71, 75 and 54 respectively. The IV 200 range in trees found in conservation areas only ranged from 6.90 to 0.29 represented by *Rinorea elleptica* and *Blighia unijugata* respectively (figure 3.18a). The IV 200 range of trees in grazing areas only was between 1.92 to 0.30 represented by *Commiphora campestris* and *Diospyros abyssinica* repectively (figure 3.18b). The IV 200 for trees found in irrigated agricultural areas only ranged between 6.81 represented by *Mangifera indica* to 0.31 represented by *Commiphora schimperi* (figure 3.18c). Among the tree species found in two or all the three types of land use (table 3.18), *Prosopis juliflora* contributed most to overall IV 200, followed by *Acacia torlitis* then *Salvadora persica.* The contribution of *Prosopis juliflora* to IV 200 was also the highest in all the land uses compared to that of other tree species. *Acacia tortilis, Salvadora persica, Dobera glabra, Grewia bicolor* and *Terminalia parvula* contributed the highest IV 200 in grazing areas compared to their contribution in the other land use areas. The contribution to IV 200 of *Maerua pubescence* was highest in conservation areas whereas in irrigated agriculture areas the contribution of *Prosopis juliflora* and *Acacia robusta* were highest compared to their contribution in other land use areas (table 3.18).

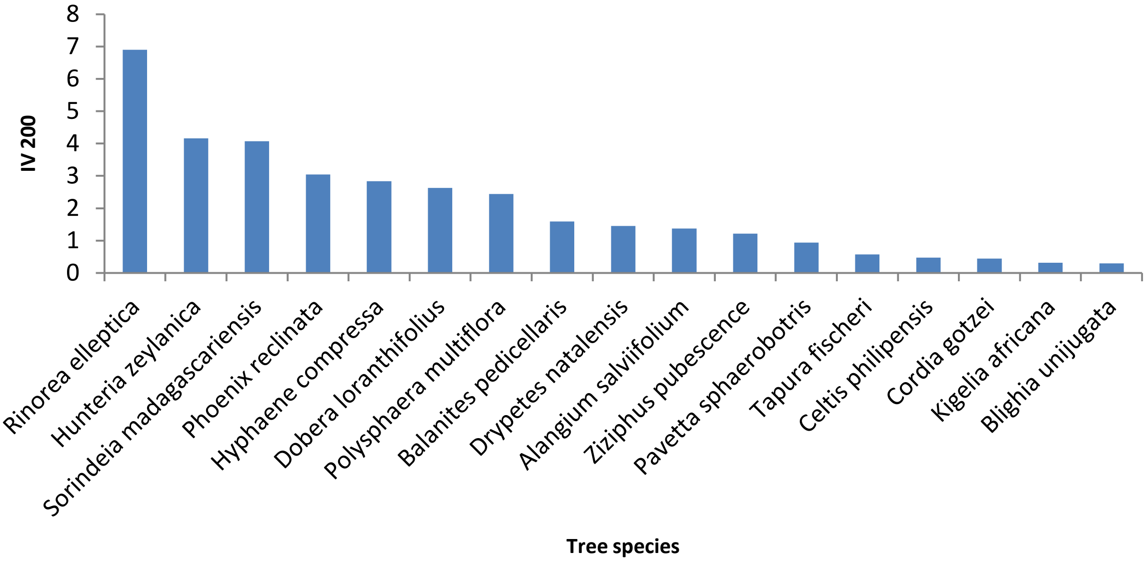

Figure 3.18a: IV 200 of tree species found only in wildlife conservation areas.

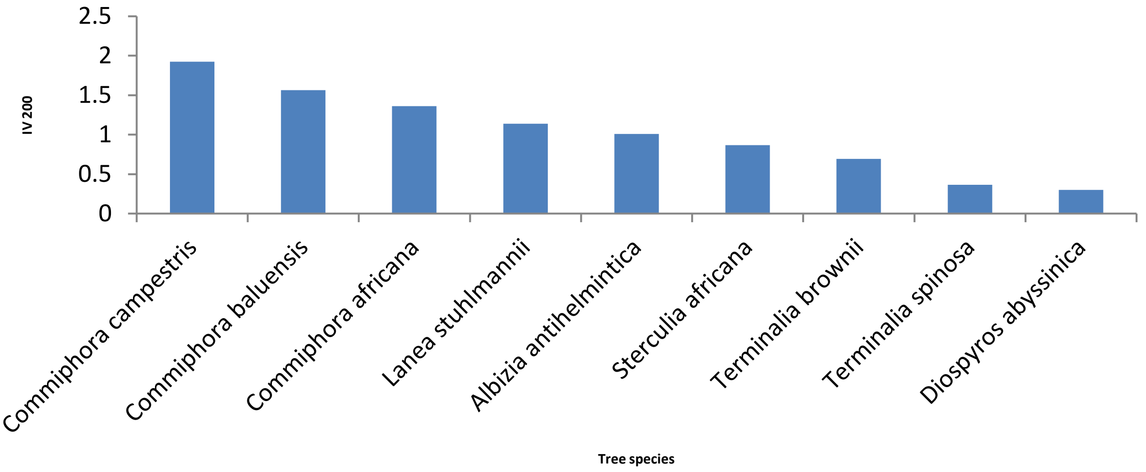

Figure 3.18b: IV 200 of tree species found only in livestock grazing areas.

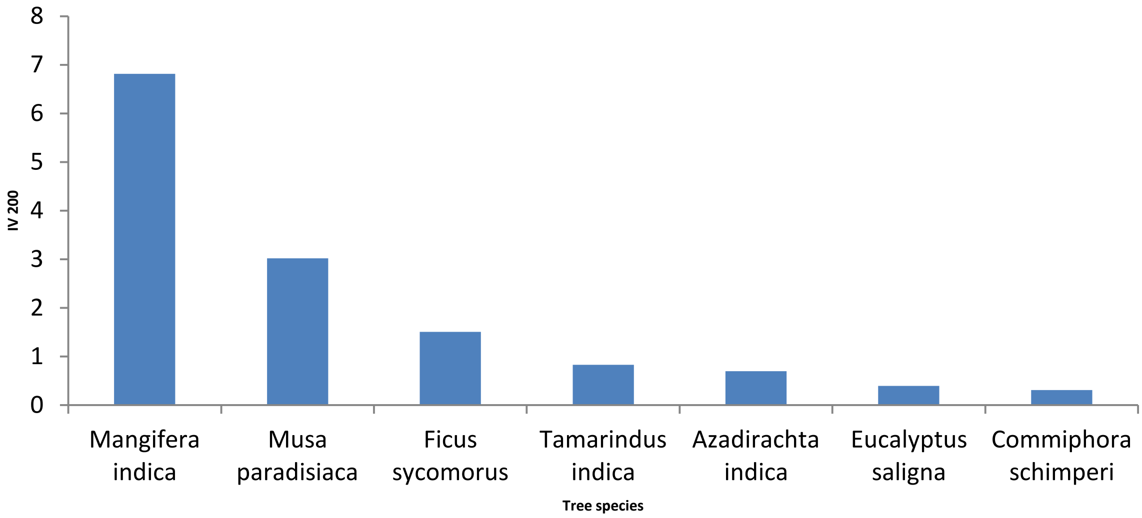

Figure 3.18c: IV 200 of tree species found only in irrigated agricultural areas.

Table 3.18: Comparison of IV 200 of tree species in more than one land use type. 0 means the species was not found in that particular land use

Plant species	Conservation	Grazing	Irrigated Agric	Total IV 200
Acacia tortilis	2.1	11.8	7.4	21.3
Acacia elatior	0	0.4	1.3	1.7
Acacia nilotica	0	1.4	0.5	1.9
Acacia robusta	0.3	0.9	1.8	3.0
Acacia zanzibarica	0	2.1	3.2	5.3
Boscia coriacea	0.6	0	0.5	1.1
Commiphora riparia	0	4.7	1.7	6.4
Dobera glabra	5.1	7.4	2.1	14.6
E. madagascariensis	0	1.1	1.0	2.1
Grewia bicolor	0.5	3.9	0.4	4.8
Lecaniodiscus fraxinifolius	5.2	0	0.8	6.0
Maerua pubescence	5.9	1.4	0.7	8.0
Prosopis juliflora	10.9	17.1	18.8	46.8
Salvadora persica	3.4	9.5	4.1	17.0
Terminalia parvula	1.5	2.6	2.3	6.4

3.5 Discussion

Vegetation dynamics are discussed based on the different categories of vegetation found inside the floodplain only, outside the floodplain only, both inside and outside the floodplain and in the different land use types (wildlife conservation, livestock grazing and irrigated agriculture).

3.5.1 Overall vegetation dynamics inside and outside the floodplain

There was no difference in the overall tree and shrub densities inside and outside the floodplain. However, inside the floodplain was richer in tree species, but poor in shrub species. This was attributed to reduced light penetration by crowns of the tall trees that slowed down seedling recruitment and growth of shorter vegetation. Indeed, though the densities of forbs and perennial grasses were significantly higher inside the floodplain, they thrived best in the gaps between the tall vegetation. Crowns of taller trees were reported to reduce the amount of light penetrating onto crowns of shorter trees, reducing their growth and seedling recruitment rates (Kohyama, 1993). Floods provide water and nutrients that enhance the growth of invasive plant species (Howell & Benson, 2000), and consequently the regeneration and growth of other plant species. Hence, the density of woody species seedlings was significant inside the floodplain despite the data having been collected at the peak of the dry season. Seasonal river flooding, according to Amoros & Bornette (2002), can act as a natural disturbance, causing a sudden alteration in natural plant communities (Resh *et al.* 1988). Regeneration of woody species, indicated by sapling and seedling density, was significant inside the floodplain, leading to a general increase in the density and richness of vegetation. This was probably due to the peak flows in the Tana River which bring along nutrient rich sediments which are spread over the floodplain. On the other hand, land clearance for crop farming resulted to significantly low overall basal area and canopy cover of trees inside the floodplain.

3.5.2 Dynamics of the vegetation found only inside the floodplain

Among the 24 tree species found only inside the floodplain, *Rinorea elleptica* had the highest density and contributed the highest to IV 200 together with *Mangifera indica.* The densities of *Mangifera indica* and *Musa paradisiaca,* and the mean basal area of *Tamarindus indica* were also high, whereas *Tapura fischeri* had the highest mean canopy cover. *Tamarindus indica*, *Mangifera indica* and *Musa paradisiaca* are fruit trees which have both domestic and commercial benefits, hence are preserved. *Thespesia danis* shrub had the highest density and occurred mainly in Arawale National Reserve and Hola in areas where livestock commonly graze in the dry season. The shrub was therefore considered an indicator of livestock disturbance. *Ricinus communis* had the highest density of saplings, while *Acacia elatior* had the highest density of seedlings. *Ricinus communis* is an invasive plant species which is commonly found in disturbed areas, hence it was also considered an indicator of disturbance. According to Hughes (1988), critical minimum flooding levels and frequency are necessary to permit successful germination and establishment of forest species, particularly in semi-arid regions. Thus, decreased river flows and reduced peak flows occasioned by climate variability would negatively impact the germination and establishment of these species. The species such as *Rinorea elleptica* and *Tapura fischeri* that were found only inside the floodplain are adapted to the conditions inside the floodplain. However, they are more susceptible to factors that influence flooding regimes, such as climate variability and flood control through construction of dams upstream. Reduction of flood quantity and alteration of peak flows by dams can affect germination and establishment of plants due to reduced water and nutrients. The government of Kenya is planning to build another mega dam along Tana River to reduce the floods but this will further reduce the volume of water and nutrients downstream, negatively affecting the vegetation. A study by Maingi and Marsh (2002) demonstrated that the construction of Masinga and Kiambere dams in 1981 and 1988 respectively had increased minimum river flow and reduced peak flow significantly. Climate variability on the other hand can lead to either droughts or floods, reducing or increasing river flows and peak flows and hence regeneration and growth of both woody and non-woody species. The species that occur only inside the floodplain at low densities are likely to be most at risk because they are specific to this particular habitat.

3.5.3 Dynamics of the vegetation found only outside the floodplain

The number of tree species found only outside the floodplain were 13, fewer than those found only inside the floodplain. The densities of individual tree species were generally lower than those of individual tree species found only inside the floodplain, with *Commiphora riparia* having the highest density. *Commiphora campestris* had the highest mean basal area and canopy cover outside the floodplain, whereas *Commiphora riparia* contributed the highest to IV 200. In the case of shrub species, the number of species found only outside the floodplain was 30, double the number found only inside the floodplain. However, except for *Salsola dendroides* whose density was high, the other shrub species occurred at relatively low densities. The high density of *Boscia coriacea* saplings indicated a high potential of regeneration and hence the species was not under any anthropogenic threat. The densities of the non-woody species and the woody species seedlings were generally quite low, not surprising since collection of data was done when it was very dry just before the long rains in March. Although these species are adapted to drier conditions, a critical minimum level of moisture is necessary for their successful germination and establishment (Stave *et al*. 2006). Thus, although changes in flooding regimes caused by construction of dams upstream would not affect them, drought linked with climate variability would negatively impact them since they depend entirely on natural precipitation for germination, establishment and growth.

Moreover, in arid and semi-arid regions, germination, emergence and survival of woody species after the dry season ends determines their existence in plant communities (Breshears & Barnes, 1999). This is because water is the main factor that limits seed germination and seedling survival in arid and semi-arid areas (Rohner & Ward, 1999; Stave *et al.* 2006). The other threats to the existence of these woody species would be anthropogenic causes such as cutting them down for charcoal burning and for construction purposes.

3.5.4 Dynamics of the vegetation found both inside and outside the floodplain

There were 11 tree species and seven shrub species that occurred both inside and outside the floodplain. The density of *Cynodon dactylon* was higher than that of other perennial grasses both inside and outside the floodplain but significantly higher inside the floodplain. Similarly, the densities of *Commelina benghalensis* and *Justicia flava* forbs were significantly higher inside compared to outside the floodplain. The species found both inside and outside the floodplain can thrive in varied moisture conditions. Moreover, the species outside the floodplain can help preserve the species in case those inside the floodplain are threatened by factors such as changes in flooding regimes. Ideally, all the plant species were expected to thrive better inside the floodplain due to higher moisture and nutrient levels (Howell & Benson, 2000). However, the densities of some of the indigenous plants such as *Acacia tortilis* and *Salvadora persica* were lower inside compared to outside the floodplain. This suggested that other factors in the floodplain limited their rate of regeneration and/or growth and therefore densities.

The density of *Prosopis juliflora,* an invasive species, was significantly higher inside the floodplain and much higher than that of the other tree species both inside and outside the floodplain. A research in the Czech Republic by Hejda *et al*. (2009) found that species diversity, richness and evenness were reduced in invaded plots. Thus, the high density of

Prosopis juliflora invader inside the floodplain could have contributed to the low densities of some of the indigenous plant species. According to Rice & Emery (2003), invasive species lead to change in the structure and composition of indigenous plant communities. Moreover, they can wipe out indigenous plants (Ortega & Pearson, 2005). A research by Gooden & French (2014) on non-interactive effects of plant invasion and landscape modification on native communities in south eastern Australia found that invasion resulted to altered community compositions and reduced rates of woody plant recruitment. Thus, the increased invasion by *Prosopis juliflora* could have led to reduced rates of recruitment, reducing the density of some of the indigenous woody species.

The mean basal areas and canopy covers for most of the tree species found both inside and outside the floodplain were relatively lower inside the floodplain. This was attributed to anthropogenic disturbances related to crop farming. The disturbances include removing branches of the large trees to allow for penetration of light and clearing of land to facilitate crop farming. *Prosopis juliflora* was the only tree whose mean basal area and canopy cover were significantly higher outside compared to inside the floodplain. This is probably because the County government has officially allowed the large *Prosopis juliflora* trees in the floodplain to be cut down for charcoal production. This measure is undertaken to reduce the density of the invader, although it sprouts back. Generally, the trees with large basal areas also had large canopy covers because the two variables are correlated with each other.

The potential of woody plant species to regenerate naturally is indicated by the density of saplings and seedlings (Mligo *et al*. 2009), which determines the species density. The density of *Prosopis juliflora* saplings and seedlings, like that of the parent plant, was higher than that of the other species both inside and outside the floodplain, but significantly higher inside compared to outside the floodplain. Davis *et al.* (2000) and Kolb *et al.* (2002) found that nutrient enrichment increased invasion and led to decreased abundance of native species. Mworia *et al.* (2011) found the establishment *of Prosopis juliflora* to be higher inside the floodplain and attributed this to the higher resources inside the floodplain. Increased availability of nutrients inside the floodplain probably increases invasion by increasing regeneration of the invader and thus its density. This then inhibits regeneration of the indigenous species, reducing their density. *Prosopis juliflora* contributed most to overall IV 200 followed by *Acacia tortilis*, *Salvadora persica* and *Dobera glabra.* Since the mean density of *Prosopis juliflora* was significantly higher and its mean basal area significantly lower inside the floodplain, its high IV 200 was attributed to its density rather than its basal area.

3.5.5 Dynamics of vegetation based on land use types

Human and livestock disturbances greatly influence the variations in species composition and diversity (Kalema & Witkowski, 2012). Of the three land uses in this study, wildlife conservation areas were least disturbed and irrigated agricultural areas were most disturbed. The findings of this study indicate that wildlife conservation areas were most tree species rich and livestock grazing areas most shrub species rich, while irrigated agricultural areas had the least number of both shrub and tree species. The overall mean densities of trees and shrubs were highest in livestock grazing areas and lowest in wildlife conservation areas, though the differences were not significant. The relatively low density of trees in wildlife conservation areas was because most of the plots in Arawale National Reserve had only shrubs implying that most trees occurred in Tana River National Primate Reserve. The low density of shrubs in wildlife conservation areas was attributed to the reduced amount of light penetrating through the crowns of the tall trees in Tana River National Primate Reserve.

Environmental degradation is caused by disturbances resulting from unsustainable land use practices (Van den Berg & Kellner, 2005). The disturbances in turn reduce the abundance and diversity of plant species thereby influencing their distribution. On the other hand, species distribution and abundance patterns at any particular site influence the species diversity (Chipman & Johnson, 2002). The tree and shrub species that were more widely distributed are those that were found in more than one land use type. Of these species, *Acacia tortilis, Salvadora persica, Dobera glabra* and *Terminalia parvula* had the highest mean densities in livestock grazing areas. The leaves of the mature and tall trees could not easily be accessed as food sources, but the fruits or ponds of some trees like *Acacia tortilis* provided food for livestock. The shrub species whose densities were highest in grazing areas were *Barleria taitensis, Salsola dendroides, Grewia tembensis, Phyllanthus sepialis, Tenantia senii, Grewia tenax, Grewia villosa, Combretum hereroense* and *Sericocomopsis hilderbrandtii* in order of decreasing density. These shrub species were probably not the preferred food for herbivores. Woody species like *Acacia elatior, Acacia robusta, Maerua pubescence, Excoecaria madagascariensis, Cadaba mirabilis, Grewia similis* and other species found in grazing areas only occurred at low densities and were probably the preferred plant foods for herbivores.

Although the density of perennial grass was high in livestock grazing areas, low species richness implied that fewer species were available for livestock feed. Moreover, there was either no perennial grass or its density was low in plots that had a high density of *Prosopis juliflora*. The high density of *Prosopis juliflora* invader may have reduced the density and species richness of perennial grass in these plots due to their reduced competitive ability (Van Auken, 2000). Getachew *et al.* (2012) found that *Prosopis juliflora* invasion in Southern Afar Rift of Ethiopia reduced the availability of grass and stocking capacity of livestock. Besides, grazing areas also had the highest density of woody species which, according to Archer &

Smeins (1991), can lead to reduced production of desirable grasses. The low density of shrubs and non-woody vegetation in wildlife conservation areas, particularly in Tana River Primate National Reserve, was due to lack of sufficient light that impeded their growth. The high density of forbs in irrigated agricultural areas was probably due to the high availability of nutrients and moisture inside the floodplain where most of the irrigated agriculture is practiced.

The relatively high density of woody species in grazing areas suggests possible woody plant encroachment. There were also more shrub species whose mean densities were higher in grazing areas than in the other land use types. Grazing areas were richest in shrub species, but the density of shrubs between the land use practices was not significantly different. Grazing pressure can cause invasion by undesirable or unpalatable plant species and lead to a decline in productivity, threatening livestock production (Angassa, 2014). This is because presence of undesirable species inevitably leads to selective grazing and browsing; thereby leading to inadequate feeds for livestock. In plots which were dominated by *Prosopis juliflora* in livestock grazing areas, no other woody or non-woody species grew underneath its canopy. This concurs with Getachew *et al.* (2012) who found that *Prosopis juliflora* impacted on plant diversity by creating a physical barrier which prevented sunlight from reaching the under canopy vegetation. Livestock grazing encourages establishment of woody plants in rangelands of dry areas (Polley *et al*. 2002) due to reduced growth and competitive ability of grasses (Van Auken, 2000). In addition, cow dung deposition by livestock can create a conducive environment for germination and survival of woody seedlings. Encroachment, coupled with favourable conditions for germination and survival of woody plant seedlings could have resulted to proliferation of *Prosopis juliflora* and other undesirable woody plant species in grazing lands.

The damage caused by human and livestock disturbances to the resident vegetation reduces its competition intensity, freeing up some resources that an invading species can take advantage of (Davis & Pelsor, 2001). The current study shows that the density of *Prosopis juliflora* seedlings was significantly high in irrigated agricultural areas hence its high density compared to the other tree species. In Tana River County, irrigated agriculture is practiced mainly inside the floodplain, where resources that support plant growth are more compared to outside the floodplain. However, the findings of this research indicate that species richness and density of woody plant species was relatively low in irrigated agricultural areas where invasion by *Prosopis juliflora* was highest. Human clearance of native woody species coupled with enhancement of water availability in pristine soil conditions favored the invasion and spread of this invasive plant. Moreover, invasive plants are more competitive for resources compared to indigenous plants (Tilman, 1997). Thus, *Prosopis juliflora* probably out-competed the remaining indigenous woody plants after land clearance, reducing their richness and densities. Some of the native woody species like *Grewia tenax, Acacia tortilis* and *Acacia nilotica* had relatively low densities because they are exploited by people for wood, charcoal and fibre.

The potential for regeneration was overall highest in irrigated agriculture areas, but higher for *Boscia coriacea* than *Prosopis juliflora*. However, regeneration of *Boscia coriacea* occurred in plots not shared with the invader, which suggests that *Prosopis juliflora* could have inhibited regeneration of indigenous plant species. The distribution of woody plant saplings and/or seedlings of species such as *Acacia tortilis, Salvadora persica* and *Dobera glabra* was mostly correlated with the distribution of the parent plants. The densities of these species were low in irrigated agricultural areas but high in livestock grazing areas. Their potential for regeneration was particularly low where they were closely associated with *Prosopis juliflora*. The high density in livestock grazing areas was due to favourable conditions created by cow dung deposition. In irrigated agricultural areas, anthropogenic disturbances such as weeding reduced the seedling density of some species. Oba *et al.* (2002) found regeneration of *Acacia tortilis* to be greater where cultivation was active than in the fallow farms in the lower Turkwel River in Kenya. In this study, the density of *Acacia tortilis* and that of its saplings and seedlings was low in irrigated agricultural areas, contradicting the above findings.

A research by Kalema & Witkowski (2012) on land use impacts on woody plant density and diversity in a savanna woodland indicated that species richness and diversity were significantly higher under charcoal production and cultivation compared with grazing. There was no invasive plant in this savanna woodland unlike in the current study where woody species abundance and richness were found to be lowest in irrigated agriculture. The findings of this study thus contradict those of Kalema & Witkowski (2012), probably because of the influence of *Prosopis juliflora* invader in irrigated areas.

The differences in the mean basal area and canopy cover of *Acacia tortilis* were significant in irrigated agriculture than in livestock and wildlife conservation areas, and also higher than those of the other tree species, an indication of its high value locally. The canopy covers and basal areas of the fruit trees such as *Mangifera indica, Tamarindus indica* and *Ficus sycomorus* found only in irrigated agriculture areas, were also relatively high. In the irrigated agricultural areas, many trees were cut down to pave way for farming, except those considered valuable by the local community. This reduced the overall tree density, basal area and canopy cover. Arawale National Reserve had mainly shrubs, reducing the overall mean basal area and canopy cover in conservation areas. However, many trees species in Tana

River National Primate Reserve such as *Maerua pubescence, Dobera glabra, Boscia coriacea* and *Lecaniodiscus fraxinifolius* had high basal and canopy covers. This was not surprising since there was minimal disturbance in wildlife conservation areas compared to livestock and irrigated agricultural areas. Although the density of *Prosopis juliflora* was relatively low in wildlife conservation areas, the trees were larger in size with wider canopies.

3.5.6 *Prosopis juliflora* invasion and indigenous plant communities

Among the plant species found both inside and outside the floodplain, *Prosopis juliflora,* an invasive species, was the only woody species whose density was significantly higher inside the floodplain. Its potential for regeneration was also quite high as shown by the density of its saplings and seedlings. A number of studies have shown that invasive plants are important determinants of vegetation composition in plant communities (Davis et al. 2000; Kolb et al. 2002; Rice & Emery, 2003; Hejda et al. 2009; Muturi *et al.* 2009; Trammell & Carreiro, 2011; Getachew *et al.* 2012; Gooden & French, 2014). Some of these studies (Muturi *et al.* 2009 and Getachew *et al.* 2012) specifically show variation in abundance of *Acacia tortilis* as determined by the presence of *Prosopis* species. In a research carried out in Turkwel riverine forest in Kenya by Muturi *et al.* (2009), the density of *Prosopis* species increased as that of *A. tortilis* dropped. This aggressive displacement of *A. tortilis* calls for prompt control of *P. juliflora* invader in order to save indigenous plant species. The current study shows that the high density of *P. juliflora* inside the floodplain may have contributed to the low density of *A. tortilis* and other indigenous tree species. Clearance of woody species to pave way for crop farming, coupled with competitive displacement by *P. juliflora,* can be a serious threat to indigenous vegetation.

Getachew *et al.* (2012) also found that *P. juliflora* invasion in Southern Afar Rift of Ethiopia had displaced and changed acacia woodlands into *P. juliflora* dominated shrub-land. In the current study, *P. juliflora* appeared to affect the density of woody plants by reducing their regeneration. This is because although it may have contributed to reduced mean densities of species like *A. tortilis* and *Salvadora persica,* their mean basal areas and canopy covers were still quite high. The large trees that were already fully established were thus not affected by *P. juliflora*. According to Getachew *et al.* (2012), *P. juliflora* impacts plant diversity by creating a physical barrier on seedlings of other species and thus prevents sunlight from reaching to the under canopy vegetation. The invader also lowers the water table and releases phytotoxins that may have negative effect on the native plant species, reducing their density and diversity.

3.6 Conclusion

The aim of this part of the study was to determine the variation in population structure of *Prosopis juliflora*, *Acacia tortilis* and other plant species with the cross-sectional floodplain gradient and land use types in Tana River County. The main land use types were wildlife conservation, Livestock grazing and irrigated agriculture. The densities and richness of trees, shrubs, saplings, seedlings and non-woody species (grasses and forbs) were compared as well as the basal area, canopy cover and importance value of the trees.

The results have shown that whereas the density of woody vegetation was similar inside and outside the floodplain, that of non-woody vegetation was higher inside the floodplain. The density of woody species was expected to be higher inside the floodplain but this was not so due to land clearance for crop farming. The potential for regeneration of woody species was higher inside the floodplain, while *P. juliflora* density and regeneration were notably higher compared to that of the indigenous trees. This invader may have contributed to reduction in the density and richness of indigenous tree species inside the floodplain. The overall basal area and canopy cover of trees were significantly higher outside the floodplain. However, the basal areas and canopy covers of the species considered valuable like *A. tortilis* were significantly higher inside the floodplain.

The shrub and tree densities were not significantly different among the three land use types. However wildlife conservation areas were the richest in tree species and livestock grazing areas the richest in shrub species. *Barleria taitensis* and *Grewia tembensis* were significantly high in livestock grazing areas, whereas *Acacia elatior* and *Prosopis juliflora* seedlings were significantly high in livestock grazing and irrigated agricultural areas respectively. For the forbs found in more than one land use types, *Commelina benghalensis* was significantly higher in irrigated agricultural areas and *Pupalia lapacea* in livestock grazing areas. The density of *Cynodon dactylon* was highest in all land use types compared to other perennial grass species.

The trees in irrigated agricultural areas contributed the least to IV 200. *P. juliflora* contributed the highest to IV 200, whereas among the indigenous tree species, *A. tortilis* contributed the highest. The order of importance of the trees was *P. juliflora, A. tortilis, Salvadora persica, Dobera glabra, Maerua pubescence, Rinorea elleptica, Mangifera indica, Commiphora riparia* and *Acacia zanzibarica.*

CHAPTER FOUR: TREE SPECIES DISTRIBUTION IN RELATION TO SOIL PROPERTIES AND LAND USES

4.1 Introduction

The Tana River, which experiences semi-annual floods, passes through the Tana River ecosystem in Tana River County, Kenya (figure 2.1). Consequently, the ecosystem can broadly be categorized into areas inside the floodplain and areas outside the floodplain. Extreme climatic events such as floods can cause variations in soil nutrients and moisture (Howell and Benson, 2000), which promote plants regeneration and growth. Thus, flooding can cause an abrupt change in natural plant communities (Resh *et al.* 1988) which can change the habitat conditions and in turn alter the composition, abundance and distribution of plant species. Land use practices influence plant species composition and diversity (Kalema & Witkowski, 2012) by altering the habitat conditions. Unsustainable land use practices can cause disturbances which can lead to environmental degradation (Van den Berg & Kellner, 2005), changing the composition, abundance and diversity of plant species.

According to Iwara *et al*. (2011), variations in edaphic conditions influence the survival and distribution patterns of flora in a given environment. Since soil properties determine the performance of plants, it follows that variations of soils inside and outside the floodplain and among land use types can influence the distribution pattern of plants. The distribution of the plants will depend on how the different species respond to a given soil property. Soil properties are related to water availability since the water absorbed by plants contains the mineral ions required by plants for growth. Thus, in dry areas water availability and soil properties are critical factors that determine plant distribution. The growth of plants and their geographic distribution is greatly affected by the environment. This is because any environmental factor that is less than ideal limits a plant's growth and/or distribution (Iwara *et al*. 2011). Programs designed for sustainable management of plants need to take into consideration the influence of soil properties on the distribution of plant species (Udoh *et al*. 2007). The soil conditions that are suitable for a particular purpose can be recognized by land use planners, farmers and horticulturists (Iwara *et al*. 2011). The knowledge may also be applied as a way to restore flora in areas threatened with desertification as well as to control the population of unwanted plant species.

According to Loth *et al.* (2005), the spatio-temporal variability in abundance of some plant species such as acacia may be explained by seed dispersal mechanisms as well as favourable soil characteristics that lead to successful establishment of seedlings. Robert *et al.* (2006) found spatial distributions of a large number of tree species in three neotropical forest plots in Colombia to be strongly associated with the distributions of soil nutrients. The influence of soil properties on the abundance and distribution of plant species has been studied by a number of researchers (Graham *et al*. 2005; Udoh *et al.* 2007; Zhou *et al.* 2010; Zare *et al*. 2011). Different soil properties have been identified in different localities that influence the distribution of specific plant species. However, the studies are not exhaustive and more studies are needed to identify and understand the dynamics of plant distribution patterns in different ecosystems.

Thus, a study was conducted in upper Tana River in Kenya to determine the effect of soil properties on the distribution of the tree species on and off the floodplain in wildlife conservation areas, livestock grazing areas and irrigated agricultural areas. This was done to understand the dynamics of tree species distribution patterns in relation to soil properties in the different areas.

4.2 Objectives

The main objective of this study was to determine the influence of soil properties on the distribution of tree species. The specific objectives were:

- To assess the variation in soil properties inside and outside the floodplain and across the main land use types (wildlife conservation, livestock grazing and irrigated agricultural areas)
- To determine the influence of soil properties on the distribution of tree species inside and outside the floodplain and among the main land use types

4.3 Materials and Methods

4.3.1 The study area

The Upper Tana River ecosystem is located in South-eastern Kenya of Tana River County (figure 2.1). The Tana River, which supplies water in this semi-arid region, experiences semi-annual floods in response to the long and short rainy seasons that occur in the river catchment area located in Mount Kenya and the Aberdare Range (Maingi, 2006). The floodplain is an asset to both farmers and livestock keepers because it contains more moisture and nutrients to support growth of crops and pasture. The main land use types are irrigated agriculture, livestock grazing and wildlife conservation. Irrigated agriculture is done mainly inside the floodplain and outside the floodplain in Hola and Bura Irrigation Schemes. Livestock grazing is done mainly outside the floodplain except during drought periods when livestock are driven into the floodplain in search of pasture. There are two conservation units in the county which serve to conserve biodiversity, Arawale National Reserve which is open to grazing and Tana River Primate Reserve which is not open to grazing.

The upper Tana River ecosystem could be under threat due to increasing cultivation and grazing intensity to support the increasing human population. Changes in flooding regime and increased drought frequencies are also a threat to the ecosystem. In addition, the region consists of pockets of large-scale invasion by *Prosopis* species, introduced in Tana River County in the early 1980s (Choge *et al*. 2002). The density of *Prosopis juliflora* was found to be significantly high in the floodplain (Mworia *et al.* 2011; Current study, chapter 3) compared to outside the floodplain. All these factors are likely to alter plant community composition and distribution due to variation in habitat conditions and anthropogenic disturbances. Besides, the impacts of grazing intensity and competition dynamics of non-indigenous and indigenous plant species are likely to change with climate, which affects flooding regimes.

4.3.2 Vegetation and Soil sampling procedures

Data were collected in Tana River Primate Reserve, Arawale National Reserve, Bura Irrigation Scheme, Hola Irrigation Scheme, Bura, Hola, Bura East, Makere, Chanani and Wenje (figure 2.2). The details of vegetation sampling were described in section 3.3. The importance value (IV), which was estimated in 10m x 10m plots by summing up relative density and relative basal area of the tree species, was used for assessment of tree species distribution. Soil samples were collected from within the 10m x 10m plots using 5cm diameter core rings which were pressed 5cm deep into the soil. The soil samples were weighed in the field using an electronic balance then put in zip-lock bags and stored in a cooler box for determination of soil moisture and bulk density. Soil samples were also collected at a depth of 0 - 20cm from within the 10m x 10m plots using a soil augur. These soil samples were put in labelled polythene bags and transferred to Kenya Agricultural Research Institute in Muguga for determination of pH, organic carbon, total nitrogen, available phosphorus and exchangeable cations (K, Na, Ca and Mg) in parts per million (ppm).

The soil variables were selected based on how important they are in supporting plant growth. As a physical soil property, bulk density is an indicator of soil compaction and influences root growth, aeration and water infiltration (Mworia *et al.* 2008). Organic carbon influences soil aggregation and together with bulk density are good indicators of soil physical structure. Soil moisture plays an important role since it determines the performance of different plants by permitting access to dissolved nutrients for plant uptake. The importance of phosphorus and nitrogen as necessary nutrients in plant growth cannot be overemphasized, while pH indicates the degree of acidity or alkalinity which also affects plant growth. CEC is a measure of the soil's ability to hold positively charged ions (cations) such as hydrogen, magnesium, potassium and calcium which is a measure of soil fertility (McKenzie *et al.* 2004).

4.3.3 Laboratory analysis of soil samples

4.3.3.1 Determination of moisture content and bulk density

The soil sampled using the 5cm diameter core rings were weighed before being oven-dried at 105°C for 24 hours. The oven-dry soil samples were then weighed to determine the moisture content based on gravimetric method outlined by Black, 1986;

Moisture content M (%) = $[\text{WWS (g)} - \text{WDS (g)}] / \text{WDS (g)} * 100$

The bulk density was determined by dividing the weight of each dry soil sample with the volume of the core-ring and multiplying by a hundred;

BD (gcm^{-3}) = $[\text{WDS (g)} / \text{VC (cm}^3)] * 100$ Where:

M = Moisture content, BD = Bulk density, WWS = Weight of wet soil

WDS= weight of dry soil, VC= Volume of core-ring

4.3.3.2 Determination of pH

The pH of a soil solution is important as it controls the available form and solubility of many plant nutrients. The ratio of water to soil was 2.5:1 whereby 50ml of deionised water was added to 20g of soil (Okalebo *et al.* 2002). The soil-water suspension was stired for 10 minutes, left to stand for 30 minutes then stired again for 2 minutes before measuring the pH.

4.3.3.3 Determination of organic carbon

The complete oxidation method was used to determine the percentage of carbon (Nelson & Sommers, 1975). The oxidation was accomplished by the internal heat of the solution and external heating using a bunsen burner. The unused or residual potassium dichromate ($K_2Cr_2O_7$) was titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$ (the difference between added and residual $K_2Cr_2O_7$) gives a measure of organic carbon content of the soil sample. The ionic equation for the carbon oxidation is shown below.

$$2Cr_2O_7^{2-} + 3C + 16H^+ = 4Cr^{3+} + 3CO_2 + 8H_2O$$

4.3.3.4 Determination of total nitrogen

Acid digestion and colorimetry were used to determine total nitrogen in the soil samples as described by Okalebo *et al.* (2002). 0.3g of air dried soil samples were weighed and placed into a digestion tube followed by 2.5ml of digestive mixture. The digestive mixture consisted of hydrogen peroxide, sulphuric acid, selenium and salicylic acid. The soil was digested at 360^oC for two hours, cooled, transferred into 50ml volumetric flask and filled to the mark with distilled water. 5.0ml of the aliquot was used for determination of total nitrogen by the colorimetric method. Colorimetry was based on modified berthelot reaction in which ammonium ions were chlorinated to monochloroamine, which then reacted with salicylate to form 5-aminosalicylate. After oxidation and oxidative coupling, a green complex was formed whose absorbance was determined at 660nm.

4.3.3.5 Determination of phosphorus

Available phosphorus was determined using the Bray 2 method as described by Okalebo *et al.* (2002). 50ml of Bray P2 extracting solution was added into a 250ml plastic bottle containing 2.50g of air-dried soil and the mixture shaken for 5 minutes. The mixture was filtered and the solution was used to determine the available soil phosphorus using colorimetric method. Standard P series solutions were prepared containing 0.0, 0.5, 1.0, 2.5, 5.0, 7.5 and 10.0 mg P per litre (ppm P). 10ml of each P standard series solutions, 10ml of each soil extract and 10ml of the blanks were pipetted into 50ml volumetric flasks followed by 20ml of distilled water and 5ml 0f 0.8M H_3BO_3 (boric acid). Beginning with the standards, 10ml of ascorbic acid was added to each flask followed by distilled water which was added to the 50ml mark. The flask was shaken to mix the contents and left undisturbed for an hour before determination of absorbance at 880nm using a colorimeter. A reagent blank and a reference sample were included in the measurements. The concentration of phosphorus was expressed as mg P kg^{-1} soil which is equivalent to parts per million (ppm).

$$\text{Concentration} = \frac{(a-b) \text{ x } v \text{ x } 1000}{1000 \text{ x } w} \ (\text{mgkg}^{-1})$$

Where a = concentration of $Pmgl^{-1}$ in extract solution, b = concentration of P mgl^{-1} in the blank sample, v = extract volume, w = weight of the air dried sample

4.3.3.6 Determination of exchangeable cations

Flame emission photometry was used for sodium and potassium whereas atomic absorption spectrophotometry was used for calcium and magnesium (Okalebo *et al.* 2002). The concentration of potassium (K), calcium (Ca) and Magnesium (Mg) in the soil sample was expressed in mgkg^{-1} (ppm).

$$\text{Concentration} = \frac{(a-b) \times v \times 1000}{1000 \times w} \ (\text{mgkg}^{-1})$$

Where a = concentration of Mg, Ca and K in the sample extract; b = concentration of the elements in the blank extract; v = volume of the extract solution; w = weight of the soil sample

4.3.3.7 Determination of Cation Exchange Capacity (CEC)

The method described by Okalebo *et al.* (2002) was used whereby cation exchange capacity was estimated by summing K^+, Ca^{2+} and Mg^{2+} previously determined with an estimate of exchangeable hydrogen measured from the buffer pH. It was expressed in centmoles per kilogram (cmolc/kg).

4.3.4 Statistical analysis of Soils

The soil variables from inside and outside the floodplain were compared using t-test whereas ANOVA was used to compare the same variables from the three land use types (Zar, 1999). Habitat preference (distribution) of tree species based on the selected soil properties was determined using canonical correspondence analysis (CCA). The Software package CANOCO version 5.0 (Ter Braak & Šmilauer, 2012) that performs best with multivariate data was used for analysis. CCA is a direct ordination technique that simultaneously uses two data sets; primary data set (species data) and secondary data set (environmental data) to relate plant community variation with environmental variables. The species data in this case was the importance value (IV) of the tree species whereas the environmental data was the soil properties. Canonical correspondence analysis accommodates multiple comparisons of many species simultaneously rather than separately using regression analysis for each species. The data files used for CANOCO analyses were generated in form of tree species and soil variable matrices using Microsoft Excel. The matrices were thereafter imported directly into CANOCO using the canoimp program. The data were then analysed and canodraws (biplots) showing the pattern of tree distribution inside and outside the floodplain and across the land use types displayed. In all the cases, CCA ordination was constrained by the measured environmental variables.

4.4 Results

4.4.1 Variation in soil characteristics inside and outside the floodplain

Comparison of the soil variables that were collected inside and outside the floodplain was as shown in table 4.1. The actual laboratory measurements for each soil property in the different locations inside and outside the floodplain are shown in appendices 1a and 1b respectively.

4.4.1.1 Bulk density (g/cm^3)

Bulk density was significantly higher ($t = -8.76$, $P < 0.05$) in soils collected outside the floodplain compared to those collected inside the floodplain (Table 4.1). The lowest bulk density recorded inside the floodplain was 1.04g/cm^3 in a soil sample collected at Tana River National Reserve and the highest was 1.5g/cm^3 in soil samples collected at Makere and Hola. These values were lower compared to those outside the floodplain where the lowest value was 1.26g/cm^3 in a soil sample collected at Wenje and the highest value was 1.87g/cm^3 in a soil sample collected at Bura East, an area predominantly used for livestock grazing.

4.4.1.2 Moisture content (%)

Moisture content in the soil samples collected inside the floodplain was significantly higher ($t = 5.92$, $P < 0.05$) than in those collected outside the floodplain (Table 4.1). Inside the floodplain, the lowest moisture content recorded was 4.8% in a soil sample collected at Bura whereas the highest was 23.0% in a soil sample collected at Chanani. The values outside the floodplain were relatively lower than those inside the floodplain. The lowest value being 1.1% in an area used for livestock grazing at Wenje and the highest 14.9% in a soil sample collected at Tana River National Reserve.

4.4.1.3 Alkalinity/Acidity test (pH)

The soils collected inside the floodplain had a significantly higher pH ($t = 2.03$, $P < 0.05$) compared to those collected outside the floodplain (Table 4.1). The lowest pH value inside the floodplain was 6.6 in a soil sample collected at Bura, an area used for livestock grazing, whereas the highest value was 8.3 in a soil sample collected at Wenje, an area used for irrigated agriculture. Outside the floodplain, the lowest pH value recorded was 4.3 at Makere in an area used for livestock grazing and the highest value was 9.2 in Bura East, an area also used for livestock grazing.

4.4.1.4 Organic carbon (%)

There was no significant difference in organic carbon content ($t = 1.21$, $P > 0.05$) between the soils collected inside the floodplain and those collected outside the floodplain (Table 4.1). Inside the floodplain, the lowest organic carbon content was 0.14% in a soil sample collected at Hola in an area used for irrigated agriculture whereas the highest was 2.75% in a soil sample collected at Wenje, an area used for livestock grazing. The lowest value outside the floodplain was also 0.10% from soil samples collected from two different areas; Hola Irrigation Scheme and Bura East (which is predominantly used for livestock grazing). The highest organic carbon content outside the floodplain was 1.87% in a soil sample collected at Wenje, an area used for livestock grazing.

4.4.1.5 Nitrogen (%)

There was no significant difference in total nitrogen content ($t = 0.80$, $P > 0.05$) between the soils collected inside the floodplain and those collected outside the floodplain (Table 4.1). The lowest nitrogen content inside the floodplain was 0.04% in a soil sample collected from four different areas at Bura East (which is used for livestock grazing), Makere, Hola, and Wenje (which are all used for irrigated agriculture) and the highest was 0.24% in a soil sample collected at Tana River National Reserve. Outside the floodplain, the lowest nitrogen content was 0.02% in a soil sample collected at Hola irrigation Scheme, whereas the highest was 0.15% in two soil samples collected at Arawale National Reserve and Makere, an area used for grazing.

4.4.1.6 Phosphorus concentration (ppm)

The concentration of phosphorus was significantly higher ($t = 5.91$, $P < 0.05$) in soil samples collected inside the floodplain compared to those collected outside the floodplain (Table 4.1). Inside the floodplain, the lowest concentration of phosphorus was 82.4ppm in a soil sample collected from Tana River National Reserve, whereas the highest concentration was 313.6ppm in a soil sample collected at Bura, an area used for irrigated agriculture. The lowest concentration of phosphorus outside the floodplain was 21.7ppm in a soil sample collected at Arawale National Reserve and the highest was 278.6ppm in a soil sample collected in Makere, an area used for livestock grazing.

4.4.1.7 Potassium concentration (ppm)

There was no significant difference in potassium concentration ($t = 1.65$, $P > 0.05$) between the soil samples collected inside the floodplain and those collected outside the floodplain (Table 4.1). The lowest concentration of potassium inside the floodplain was 344.4ppm in a soil sample collected at Tana River National Reserve, whereas the highest was 1480.9ppm in a sample collected at Chanani, an area used for irrigated agriculture. Outside the floodplain, the lowest concentration of potassium was 68.9ppm in a soil sample collected at Wenje in an area used for livestock grazing and the highest was 2204.1ppm in a soil sample collected at Bura Irrigation Scheme.

4.4.1.8 Magnesium concentration (ppm)

The soil samples collected inside the floodplain had significantly higher concentration of magnesium ($t = 3.25$, $P < 0.05$) compared to those collected outside the floodplain (Table 4.1). The lowest concentration of magnesium inside the floodplain was 293.0ppm in a soil sample collected at Makere, an area used for irrigated agriculture whereas the highest was 1188.2ppm in a soil sample collected at Chanani, also an area used for irrigated agriculture. Outside the floodplain, the lowest concentration was 115.6ppm in a soil sample collected at Wenje in an area used for livestock grazing, and the highest was 1201.6ppm in a soil sample collected at Bura Irrigation Scheme.

4.4.1.9 Calcium concentration (ppm)

The soil samples collected inside the floodplain had significantly higher concentration of calcium ($t = 2.04$, $P < 0.05$) compared to those collected outside the floodplain (Table 4.1). The lowest concentration of calcium inside the floodplain was 928.8ppm in a soil sample collected at Tana River National Reserve whereas the highest was 3993.7ppm in a soil sample collected at Chanani, an area used for irrigated agriculture. Outside the floodplain, the lowest concentration was 185.8ppm in a soil sample collected at Wenje, an area used for livestock grazing. The highest concentration outside the floodplain was 5015.3ppm in a soil sample collected at Arawal National Reserve.

4.4.1.10 Cation Exchange Capacity/CEC (centmoles/kg)

There was no significant difference in CEC (t = 1.87, P > 0.05) between the soil samples collected inside the floodplain and those collected outside the floodplain (Table 4.1). Inside the floodplain, the lowest CEC value was 5.2 centmoles/kg in a soil sample collected at Tana River National Reserve. The highest value was 18.9 centmoles/kg in a soil sample collected at Chanani, an area used for irrigated agriculture. Outside the floodplain, the lowest CEC value was 1.6 centmoles/kg in a soil sample collected at Wenje, an area used for livestock grazing and the highest value was 28.7 centmoles/kg in a sample collected at Arawale National Reserve.

Table 4. 1: Comparison of soil variables inside and outside the floodplain (Mean±SE)

Soil variable	In floodplain	Outside floodplain	t-value	P-value
Bulk density	1.27±0.03	1.59±0.03	-8.759	0.000***
Moisture	12.38±0.81	6.28±0.64	5.923	0.000***
pH	7.65±0.09	7.19±0.20	2.032	0.047**
Organic Carbon	1.04±0.93	0.86±0.09	1.206	0.232
Nitrogen	0.10±0.01	0.09±0.01	0.797	0.429
Phosphorus	174.31±6.84	101.65±10.23	5.905	0.000***
Potassium	927.63±61.00	727.66±105.09	1.646	0.105
Magnesium	715.49±50.65	496.10±44.75	3.246	0.002**
Calcium	2636.49±165.51	1989.35±270.21	2.042	0.046**
CEC	12.79±0.79	10.08±1.22	1.873	0.066

*** Very significant

** Significant

4.4.2 Variation in soil characteristics across land use types

The variation in soil characteristics across the three land use types was as shown in table 4.2. The actual laboratory measurements for each soil characteristic per land use in the different locations are shown in appendices 2a, 2b and 2c.

4.4.2.1 Bulk density (g/cm^3)

Bulk density was significantly higher ($F = 4.13$, $P < 0.05$) in livestock grazing areas compared to conservation and irrigated agricultural areas (Table 4.2). Bulk density in areas used for livestock grazing ranged from 1.08g/cm^3 in a soil sample collected inside the floodplain at Bura East to 1.87g/cm^3 in a soil sample collected outside the floodplain at Bura. Bulk density was second highest in conservation areas and ranged from 1.04g/cm3 in a sample of soil collected in the floodplain at Tana River National Reserve to 1.86/cm3 in a soil sample collected outside the floodplain at Arawale National Reserve. Soils collected from irrigated agricultural areas had the lowest bulk density that ranged from 1.11g/cm3 in a sample of soil collected in the floodplain at Hola to 1.68g/cm3 in a sample of soil collected in the floodplain at Chanani.

4.4.2.2 Moisture content (%)

There was no significant difference ($F = 2.18$, $P > 0.05$) in moisture content between the three land uses (Table 4.2). Moisture content in irrigated agricultural areas ranged from 2.34% in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 22.99% in a soil sample also collected inside the floodplain at Hola. Conservation areas had the second highest moisture content that ranged from 3.50% in a soil sample collected outside the floodplain at Arawale National Reserve to 14.96% in a soil sample collected inside the floodplain at Tana River National Reserve. Livestock grazing areas had the lowest moisture content ranging from 1.34% in a soil sample collected outside the floodplain at Bura East to 16.53% in a soil sample collected inside the floodplain at Makere.

4.4.2.3 Alkalinity/Acidity (pH)

There was no significant difference (F = 1.02, P > 0.05) in soil pH between the three land uses (Table 4.2). Irrigated agricultural areas had the highest pH value that ranged from 6.4 in a sample of soil collected in the floodplain at Chanani to 8.4 in a sample also collected in the floodplain at Wenje. Livestock grazing areas had the second highest pH value that ranged from 4.3 in a sample of soil collected in the floodplain at Wenje to 8.4 in a sample of soil also collected in the floodplain at Bura. The lowest pH value was in conservation areas and ranged from 5.8 in a soil sample collected outside the floodplain to 9.2 in a sample collected outside the floodplain, both at Arawale National Reserve.

4.4.2.4 Organic carbon (%)

The difference in organic carbon content between the three land uses was not significant (F = 1.41, P > 0.05) (Table 4.2). Organic carbon was highest in conservation areas and ranged from 0.42% in a soil sample collected outside the floodplain at Arawale National Reserve to 2.59% in a soil sample collected inside the floodplain at Tana River National Reserve. Livestock grazing areas were the second highest in organic carbon content that ranged from 0.10% in a soil sample collected inside the floodplain to 2.75% in a soil sample collected outside the floodplain, both at Bura. The lowest organic carbon content was in irrigated agricultural areas and ranged from 0.10% in a sample of soil collected in the floodplain at Chanani to 1.63% in a sample also collected in the floodplain at Makere.

4.4.2.5 Nitrogen (%)

The difference in total nitrogen between the three land uses was significant (F = 3.61, $P < 0.05$) (Table 4.2). Post hoc analysis indicated that the difference was specifically between conservation and irrigated agricultural areas. Nitrogen content was highest in conservation areas and ranged from 0.06% in a soil sample collected outside the floodplain at Arawale National Reserve to 0.24% in a soil sample collected inside the floodplain at Tana River National Reserve. Livestock grazing areas were the second highest in nitrogen content that ranged from 0.04% in two different soil samples collected inside the floodplain at Bura to 0.17% in a soil sample collected outside the floodplain at Bura East. Irrigated agricultural areas had the lowest nitrogen content that ranged from 0.02% in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 0.14% in a soil sample also collected inside the floodplain at Makere.

4.4.2.6 Phosphorus concentration (ppm)

There was a significant difference (F = 5.33, $P < 0.05$) in concentration of phosphorus between the three land uses (Table 4.2). Post hoc analysis revealed that the difference was between irrigated agricultural and conservation areas. The highest concentration of phosphorus was in irrigated agricultural areas and ranged from 38.0ppm in a soil sample collected outside the floodplain in Bura Irrigation Scheme to 313.6ppm in a soil sample collected inside the floodplain at Bura. The second highest concentration of phosphorus was in livestock grazing areas and ranged from 40.0ppm in a soil sample collected outside the floodplain at Bura East to 278.6ppm in a soil sample collected also outside the floodplain at Makere. Conservation areas had the lowest concentration of phosphorus that ranged from 21.7ppm in a soil sample collected outside the floodplain at Arawale National Reserve to 189.9ppm in a soil sample collected inside the floodplain at Tana River National Reserve.

4.4.2.7 Potassium concentration (ppm)

There was no significant difference (F = 0.91, P > 0.05) in the concentration of potassium between the three land uses (Table 4.2). Potassium concentration was highest in irrigated agricultural areas and ranged from 241.1ppm in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 2204.1ppm outside the floodplain at Bura Irrigation Scheme. Conservation areas were the second highest in potassium concentration and ranged from 137.8ppm in a soil sample collected outside the floodplain at Tana River National Reserve to 1894.1ppm also collected outside the floodplain at Arawale National Reserve. The lowest potassium concentration was in livestock grazing areas and ranged from 68.9ppm in a soil sample collected outside the floodplain at Wenje to 1446.4ppm in a soil sample collected inside the floodplain at Bura.

4.4.2.8 Magnesium concentration (ppm)

There was no significant difference (F = 0.42, P > 0.05) in the concentration of magnesium between the three land uses (Table 4.2). The highest concentration of magnesium was in irrigated agricultural areas and ranged from 212.4ppm in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 1201.6ppm in a soil sample also collected outside the floodplain at Bura Irrigation Scheme. Conservation areas were the second highest in concentration of magnesium ranging from 231.2ppm in a soil sample collected outside the floodplain at Tana River National Reserve to 1094.1ppm in a soil sample collected inside the floodplain at Arawale National Reserve. The lowest magnesium concentration was in livestock grazing areas and ranged from 115.6ppm in a soil sample collected outside the floodplain at Wenje to 1158.6ppm in a soil sample collected inside the floodplain at Bura.

4.4.2.9 Calcium concentration (ppm)

There was no significant difference (F = 0.69, P > 0.05) in calcium concentration between the three land uses (Table 4.2). The highest concentration of calcium was in irrigated agricultural areas and ranged from 650.1ppm in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 5386.8ppm in a soil sample also collected outside the floodplain at Bura Irrigation Scheme. The second highest concentration of calcium was in conservation areas and ranged from 371.5ppm in a soil sample collected outside the floodplain at Tana River National Reserve to 5015.3ppm in a soil sample also collected outside the floodplain at Arawale National Reserve. The lowest concentration of calcium was in livestock grazing areas and ranged from 185.8ppm in a soil sample collected outside the floodplain at Wenje to 3900.8ppm in a soil sample collected inside the floodplain at Bura.

4.4.2.10 Cation exchange capacity/CEC (centmoles/kg)

There was no significant difference (F = 0.52, P > 0.05) in the CEC of soils between the three land uses (Table 4.2). The highest CEC was from soils in irrigated agricultural areas and ranged from 3.7 centmoles/kg in a soil sample collected outside the floodplain at Hola Irrigation Scheme to 24.2 centmoles/kg in a soil sample also collected outside the floodplain at Bura Irrigation Scheme. The second highest in CEC were soils in conservation areas that ranged from 2.8 centmoles/kg in a soil sample collected outside the floodplain at Tana River National Reserve to 28.7 centmoles/kg in a soil sample also collected outside the floodplain at Arawale National Reserve. The lowest CEC was from soils in livestock grazing areas that ranged from 1.6 centmoles/kg in a soil sample collected outside the floodplain at Wenje to 19.0 centmoles/kg in a soil sample collected inside the floodplain at Bura.

Table 4.2: Comparison of soil variables across land use types (Mean±SE).

Soil variable	Conservation	Grazing	Irrig. Agric	F-value	P-value
Bulk density	1.46±0.05	1.49±0.04	1.32±0.05	4.125	0.021
Moisture	9.42±1.14	7.81±1.04	10.98±1.11	2.181	0.122
pH	7.26±0.21	7.35±0.19	7.65±0.20	1.023	0.366
Org. Carbon	1.09±0.14	0.98±0.12	0.78±0.13	1.405	0.254
Nitrogen	0.11±0.01	0.09±0.01	0.07±0.01	3.612	0.033
Phosphorus	106.99±12.97	139.16±11.79	166.06±12.64	5.328	0.007
Potassium	819.28±111.43	738.19±101.28	938.46±108.61	0.913	0.407
Magnesium	612.90±66.28	565.45±60.24	645.43±64.60	0.418	0.660
Calcium	2317.02±295.03	2095.78±268.15	2558.74±287.56	0.693	0.504
CEC	11.89±1.35	10.45±1.22	12.14±1.31	0.524	0.595

4.4.3 Gradient analysis of vegetation and soil data using Canonical Correspondence Analysis

Canonical Correspondence Analysis (CCA) showed that the distribution pattern of the tree species was related to the variation in the soil characteristics. This applied both inside and outside the floodplain as well as in conservation, livestock grazing and irrigated agricultural areas. The ordination diagrams (biplots) show the correlations of soil variables with tree species (figures 4.1, 4.2, 4.3, 4.4, 4.5). The correlations between the tree species and the environmental (soil) variables showed how variation in plant community composition was explained by the soil properties. The arrows represent the soil characteristics and point in the direction of maximum correlation across the ordination diagram. The direction of the vector indicates its correlation with each of the axes and thus with the plant community variation shown by the ordination diagram. The CCA axes in the ordination diagrams are linear combinations of the explanatory variables. Other outputs of CCA are the eigenvalues which are associated with each of the axis and indicate the fraction of the total constrained inertia. Thus, eigenvalues express the amount of the constrained inertia that is expressed by each constrained axis. The strength of the relationship between the soil properties and the tree species is shown by the canonical correlations whereas the % variation indicates the environmental variation that each axis explains. Monte-Carlo permutation is a test of significance on the canonical axes to determine which of the axes represent variation that can be distinguished from random.

The soil variables (environmental data) were pH, nitrogen (N), phosphorus (P), magnesium (Mg), calcium (Ca), potassium (K), organic carbon (C), bulk density (BD), moisture (Mois) and cation exchange capacity (CEC). In all the biplots, the species are denoted by a four code letter where the first two letters represent the generic name and the last two letters the specific name.

4.4.3.1 CCA of tree species and soil data from inside the floodplain

The total variation (inertia) inside the floodplain was 10.96, with explanatory variables accounting for 4.035 meaning that the unexplained variation accounted for 6.925 (table 4.3). The eigenvalue of the first axis was the highest, progressively decreasing in the other axes, implying that this axis was the strongest and the most important gradient in explaining the influence of soil characteristics on tree species distribution pattern inside the floodplain. However, the eigenvalues of the second and third axes were also high. This implied that the second and third axes were also important in explaining the influence of soil characteristics on tree species distribution pattern inside the floodplain. The first CCA axis explained the highest fitted variation (species-environment relation) of 22.7% of the total variation in the data set, with the first three CCA axes explaining 58.5% (table 4.3).

Monte Carlo permutation test for all the CCA axes showed that the soil variables had insignificant influence ($P > 0.05$) on the tree species distribution pattern inside the floodplain. However, the same test on the first axis indicated that the soil variables had a significant influence ($P < 0.05$) on the distribution of tree species (Table 4.3). Further analysis for individual variables showed that pH, bulk density, potassium, calcium and CEC significantly influenced ($P < 0.05$) tree species distribution pattern inside the floodplain (Table 4.4).

Table 4.3: Summary results of the first four CCA-axes of data from inside the floodplain. Sig. = significant; Total variation = sum of all unconstrained eigenvalues.

Axes	1	2	3	4	Total variation
CCA-Eigenvalues	0.916	0.831	0.615	0.447	10.960
Explained variation (Cumulative%)	8.4	15.9	21.6	25.6	
Explained fitted variation (Cumulative %)	22.7	43.3	58.5	69.6	
Canonical correlation	0.975	0.978	0.879	0.880	
All unconstrained eigenvalues					10.960
All canonical eigenvalues					4.035
Monte Carlo Permutation test	F-ratio	P-value	Conclusion		
CCA axis 1	1.7	0.002	Significant		
All CCA axes	1.1	0.220	Not Sig.		

Table 4.4: Monte Carlo Permutation test results for significance of soil variables from inside the floodplain. Sig. = Significant

Variable	Variance	F-ratio	P-value	Conclusion
Moisture	0.056	0.6	0.94	Not significant
pH	0.187	2.1	0.002	Significant
Bulk density	0.138	1.5	0.05	Significant
Nitrogen	0.092	1.0	0.462	Not significant
Phosphorus	0.126	1.4	0.176	Not significant
Organic Carbon	0.097	1.0	0.382	Not significant
Magnesium	0.120	1.3	0.094	Not significant
Potassium	0.151	1.6	0.004	Significant
Calcium	0.153	1.7	0.006	Significant
CEC	0.141	1.5	0.02	Significant

The variables that were negatively strongly correlated with the first axis inside the floodplain were pH (CCA-axis 1, $r = -0.805$), potassium (CCA-axis1, $r = -0.684$), magnesium (CCA-axis 1, $r = -0.574$), calcium (CCA-axis 1, $r = -0.664$) and CEC (CCA-axis 1, $r = -0.633$) (table 4.5). The variable which was most important in axis 1 was pH with the highest r value and longest arrow in ordination space compared to the other variables (figure 4.1). The first axis was therefore a gradient saturated with bases whose availability was strongly influenced by a pH gradient. Consequently, CEC, which is dependent on available bases, varied with the pH gradient. The tree species that were correlated with high pH, CEC and high concentrations of calcium, magnesium and potassium along the first axis were *Acacia elatior, Acacia nilotica, Acacia tortilis, Prosopis juliflora, Tamarinda indica, Mangifera indica, Maerua pubescence, Eucalyptus saligna, Salvadora persica, Lecaniodiscus fraxinifolius, Azadirachta indica* and *Dobera loranthifolius* (figure 4.1). However, a number of tree species were negatively correlated with increasing bases, pH and CEC. These species included *Dobera glabra, Musa paradisiaca, Terminalia parvula, Drypetes natalensis, Kigelia africana, Ziziphus pubescence, Blighia unijugata, Polysphaera multiflora, Hunteria zeylanica, Rinorea elleptica, Celtis philipensis, Alangium salviifolium, Phoenix reclinata* and *Tapura fischeri.* Thus, the tree species that were positively correlated with the first axis thrived well in soils with a low concentration of bases, low pH and low CEC. On the other hand, the tree species that were negatively correlated with this axis thrived well in soils with high concentration of bases, high pH and high CEC.

Table 4.5: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species inside the floodplain. Shown in bold are the soil properties with strong correlation coefficients to each axis.

Variable	Axis 1	Axis 2	Axis 3
Bulk density	-0.409	**-0.640**	0.031
Moisture	0.060	0.082	-0.111
pH	**-0.805**	-0.208	0.118
Organic carbon	-0.046	**0.417**	0.347
Nitrogen	0.040	0.238	0.301
Phosphorus	-0.255	-0.236	**-0.551**
Potassium	**-0.684**	0.221	-0.091
Magnesium	**-0.574**	0.160	-0.098
Calcium	**-0.664**	0.311	-0.047
CEC	**-0.633**	0.281	-0.009

Bulk density (CCA-axis 2, r = -0.640) and organic carbon (CCA-axis 2, r = 0.417) were strong negatively and positively correlated with axis 2 respectively. Hence, the second axis was a soil compaction axis in which increasing bulk density resulted to decline in organic carbon. The tree species that were correlated with increasing bulk density and declining organic carbon along the second axis were *Prosopis juliflora, Acacia tortilis, Acacia zanzibarica, Acacia elatior, Excoecaria madagascariensis* and *Musa paradisiaca.* On the other hand, low bulk density and high organic carbon were correlated with *Acacia robusta, Ficus sycomorus, Hyphaene compressa, Diospyros abyssinica, Sorindeia madagascariensis, Cordia gotzei* and *Pavetta sphaerobotris.* The tree species that were positively correlated with the second axis grew in soils that were rich in organic carbon and low bulk density. The tree species that were negatively correlated with this axis grew in soils with high bulk density and low organic carbon.

Phosphorus was negatively and strongly correlated with the third axis (CCA-axis 3, r = -0.551), but negatively and weakly correlated with the first axis (CCA-axis1, r = -2.55) (table 4.5). Phosphorus was also negatively correlated with moisture in ordination space along the first axis. Thus, the trees species that were correlated with increasing phosphorus concentration along the first axis were also correlated with decreasing moisture. They included *Acacia tortilis, Acacia elatior, Acacia zanzibarica, Prosopis juliflora, Dobera glabra, Terminalia pervula, Musa paradisiaca* and *Excoecaria madagascariensis* (figure 4.1). On the other hand, the tree species that were correlated with decreasing phosphorus were correlated with increasing moisture. Among them were *Cordia gotzei, Diospyros abyssinica, Pavetta sphaerobotris, Sorindeia madagascariensis, Ficus sycomorus, Hyphaene compressa, Salvadora persica, Lecaniodiscus fraxinifolius, Azadirachta indica* and *Dobera loranthifolia.*

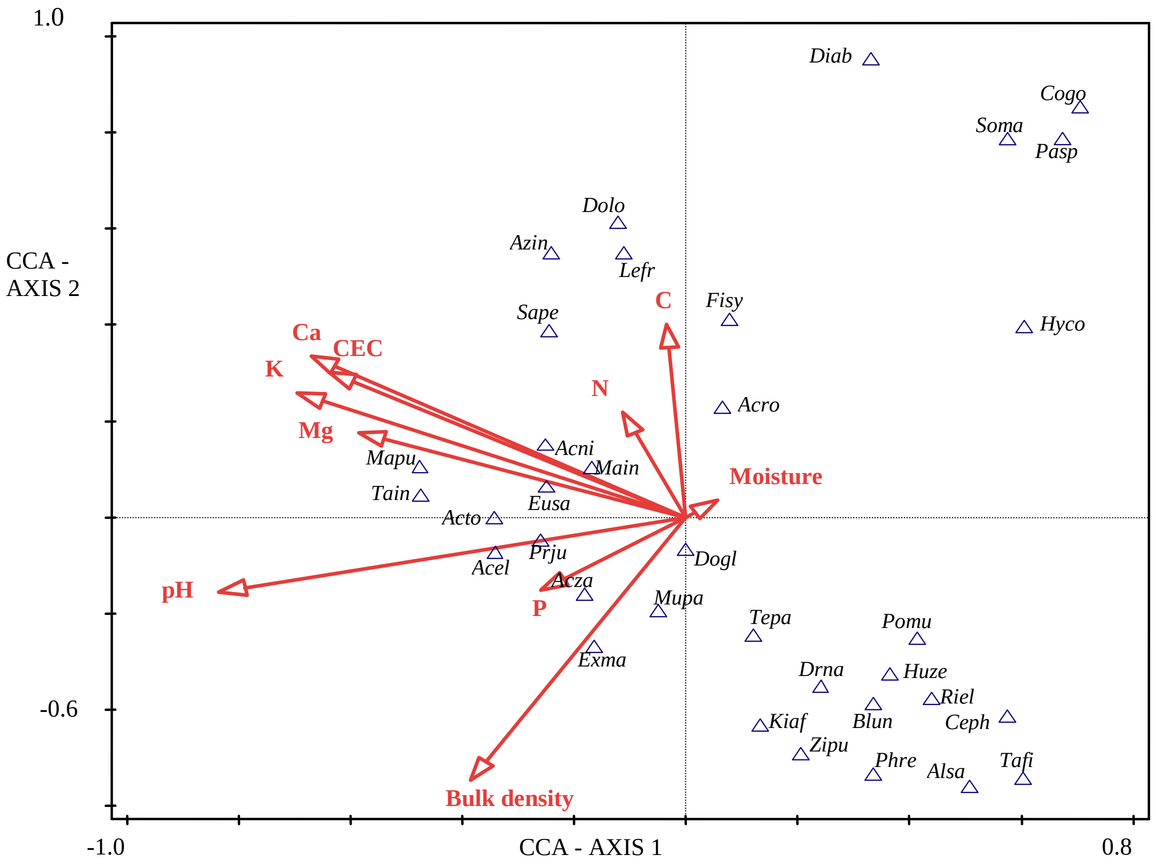

Figure 4.1: CCA biplot showing the influence of soil variables on tree species distribution patterns inside the floodplain. The arrows represent the soil variables and the triangles the tree species which are denoted by a four code letter where the first two letters represent the generic name and the last two letters the specific name. The species are *Acacia elatior (Acel), Acacia nilotica (Acni), Acacia robusta (Acro), Acacia tortilis (Acto), Acacia zanzibarica (Acza), Alangium salviifolium (Alsa), Azadirachta indica (Azin), Blighia unijugata (Blun), Celtis philipensis (Ceph), Cordia gotzei (Cogo), Diospyros abyssinica (Diab), Dobera glabra (Dogl), Dobera loranthifolia (Dolo), Drypetes natalensis (Drna), Eucalyptus saligna (Eusa), Excoecaria madagascariensis (Exma), Ficus sycomorus (Fisy), Hunteria zeylanica (Huze), Hyphaene compressa (Hyco), Kigelia africana (Kiaf), Lecaniodiscus fraxinifolius (Lefr), Maerua pubescence (Mapu), Mangifera indica (Main), Musa paradisiaca (Mupa), Pavetta sphaerobotris (Pasp), Phoenix reclinata (Phre), Polysphaera multiflora (Pomu), Prosopis juliflora (Prju), Rinorea elleptica (Riel), Salvadora persica (Sape), Sorindeia madagascariensis (Soma), Tamarindus indica (Tain), Tapura fischeri (Tafi), Terminalia parvula (Tepa)* and *Ziziphus pubescence (Zipu).*

4.4.3.2 CCA of tree species and soil data from outside the floodplain

Outside the floodplain, the total variation (inertia) was 7.23, with explanatory variables accounting for 3.10 meaning that the unexplained variation accounted for 4.13 (table 4.6). The eigenvalue of the first axis was the highest, though less compared to that of the same axis inside the floodplain. This implied that the first axis represented the strongest and the most important gradient in explaining the influence of soil characteristics on tree species distribution outside the floodplain. The first CCA axis also explained the highest fitted variation of 21.0% of the total variation in the data set, with the first three CCA axes explaining 51.7% (table 4.6).

Monte Carlo permutation test on all the axes and on the first axis indicated that in both cases the influence of soil properties on the tree species distribution pattern outside the floodplain was marginal ($0.05 < P \leq 0.1$) (table 4.6). Permutation tests on individual variables showed that Moisture, bulk density, Phosphorus, potassium, calcium, magnesium and CEC influenced the tree species distribution significantly ($P < 0.05$) (table 4.7). Nitrogen and organic carbon were not significant ($P > 0.05$) on the tree species distribution (table 4.7).

Table 4.6: Summary results of the first four CCA-axes of data from outside the floodplain. Total variation = sum of all unconstrained eigenvalues.

Axes	1	2	3	4	Total variation
CCA-Eigenvalues	0.652	0.511	0.438	0.377	7.229
Explained variation (Cumulative %)	9.0	16.1	22.2	27.4	
Explained fitted variation (Cumulative %)	21.0	37.5	51.7	63.8	
Canonical correlation	0.972	0.911	0.924	0.828	
All unconstrained eigenvalues					7.229
All canonical eigenvalues					3.101
Monte Carlo Permutation test	F-ratio	P-value	Conclusion		
CCA Axis 1	1.8	0.082	Not significant		
All CCA Axes	1.2	0.100	Not significant		

Table 4.7: Monte Carlo Permutation test results for significance of soil variables from outside the floodplain.

Variable	Variance	F-ratio	P-value	Conclusion
Moisture	0.122	1.5	0.026	Significant
pH	0.116	1.5	0.136	Not significant
Bulk density	0.135	1.7	0.010	Significant
Nitrogen	0.109	1.4	0.072	Not significant
Phosphorus	0.158	1.7	0.016	Significant
Org. Carbon	0.116	1.5	0.062	Not significant
Magnesium	0.180	2.3	0.004	Significant
Potassium	0.180	2.3	0.002	Significant
Calcium	0.175	2.0	0.002	Significant
CEC	0.177	2.3	0.002	Significant

The variables that were strongly correlated with the first axis outside the floodplain were pH (CCA-axis1, r = 0.558), potassium (CCA-axis1, r = 0.848), magnesium (CCA-axis1, r = 0.869), calcium (CCA-axis1, r = 0.824), CEC (CCA-axis1, r = 0.839), moisture (CCA-axis1, r = 0.475) and bulk density (CCA-axis1, r = -0.513) (table 4.8). Like inside the floodplain, the first axis was a gradient of available bases whose availability was strongly influenced by a pH gradient. As a consequent, CEC which is dependent on available bases varied with the pH gradient. The first axis was also a soil compaction gradient in which an increase in bulk density resulted to a decrease in moisture and vice versa. The tree species which were correlated with increasing bases, pH, CEC, moisture and decreasing bulk density were *Acacia zanzibarica, Acacia robusta, Terminalia brownii, Prosopis julifora, Maerua pubescence, Commiphora campestris* and *Commiphora schimperi* (Figure 4.2). These trees grew in soils which had high pH (basic) due to a high concentration of bases, high CEC, adequate moisture and low bulk density. Most of the trees species were correlated with decreasing bases, pH, CEC, water and increasing bulk density. They included *Acacia nilotica, Acacia tortilis, Albizia anthelmintica, Balanites pedicellaris, Boscia coriacea, Commiphora africana, Commiphora baluensis, Commiphora riparia, Dobera glabra, Dobera loranthifolius, Grewia bicolor*, *Lanea stuhlmannii*, *Lecaniodiscus fraxinifolius, Salvadora persica, Sterculia africana, Terminalia parvula* and *Terminalia spinosa.* These tree species thrived better in soils with a low concentration of bases and thus low pH and CEC, low moisture and high bulk density.

Table 4.8: Correlation coefficients of soil properties with the ordination axes indicating their influence on the distribution of tree species outside the floodplain. Shown in bold are the soil properties with strong correlation coefficients to each axis.

Variable	Axis 1	Axis 2	Axis 3
Bulk density	**-0.513**	-0.336	0.221
Moisture	**0.475**	-0.152	-0.420
pH	**0.558**	0.230	-0.195
Organic carbon	-0.070	0.324	**0.516**
Nitrogen	0.154	**0.711**	0.197
Phosphorus	-0.020	**0.758**	-0.125
Potassium	**0.848**	0.219	0.084
Magnesium	**0.869**	0.068	0.120
Calcium	**0.824**	0.251	0.106
CEC	**0.839**	0.219	0.128

Phosphorus (CCA-axis 2, r = 0.758) and nitrogen (CCA-axis 2, r = 0.711) were strong positively correlated with axis 2, with the former variable having the highest correlation coefficient (table 4.8). The tree species that were correlated with increasing levels of phosphorus and nitrogen were *Albizia anthelmintica, Acacia nilotica, Salvadora persica, Sterculia africana, Commiphora baluensis, Lannea stuhlmannii, Acacia robusta, Commiphora campestris and Terminalia brownie* (Figure 4.2). These trees grew in soils that were rich in phosphorus and nitrogen. On the other hand, the tree species that were correlated with decreasing levels of phosphorus and nitrogen grew in soils that were relatively poor in these variables. They included *Acacia tortilis, Acacia zanzibarica, Balanites pedicellaris, Boscia coriacea, Commiphora africana, Commiphora riparia, Commiphora schimperi, Dobera glabra, Dobera loranthifolius, Grewia bicolor, Lecaniodiscus fraxinifolius, Maerua pubescence, Prosopis julifora, Terminalia parvula* and *Terminalia spinosa.*

Organic carbon (CCA-axis 3, r = 0.516) was strongly positively correlated with axis 3. But it was also correlated with the second and fourth species axes (CCA-axis 2, r = 0.324; CCA-axis 4, r = -0.395) (table 4.8). The tree species that were correlated with increasing levels of organic carbon were also correlated with increasing levels of phosphorus and nitrogen, while those that were correlated with decreasing levels of organic carbon were also correlated with decreasing levels of phosphorus and nitrogen.

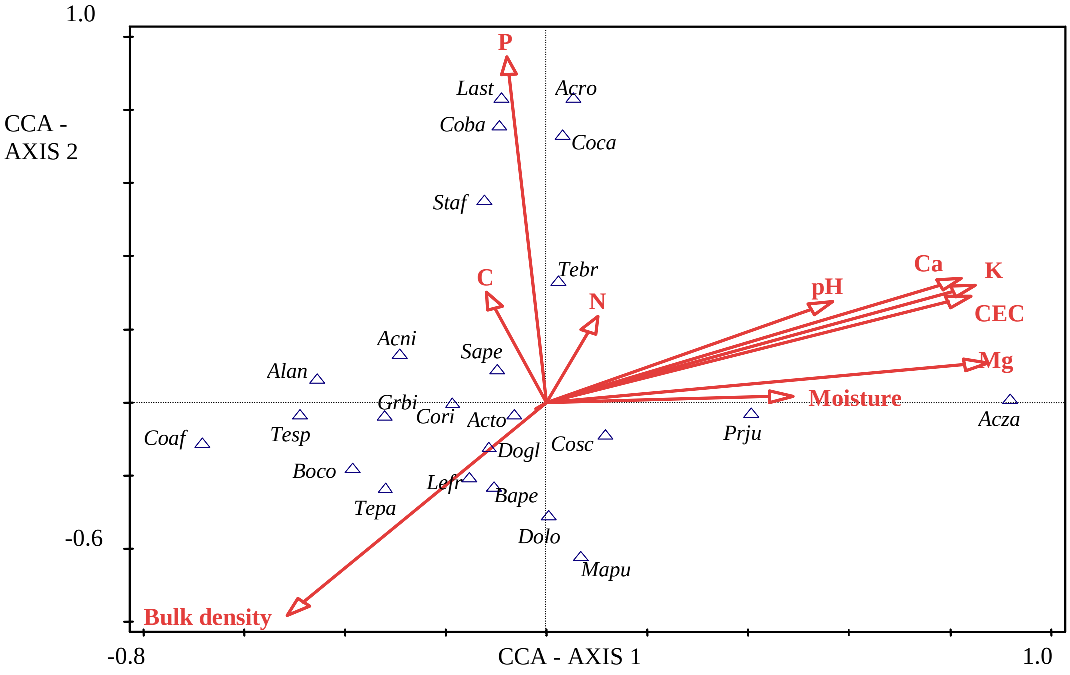

Figure 4.2: CCA biplot showing the influence of soil variables on tree species distribution patterns outside the floodplain. The arrows represent the soil variables and the triangles the tree species which are denoted by a four code letter where the first two letters represent the generic name and the last two letters the specific name. The tree species are *Acacia nilotica (Acni), Acacia robusta(Acro), Acacia tortilis (Acto), Acacia zanzibarica (Acza), Albizia anthelmintica (Alan), Balanites pedicellaris (Bape), Boscia coriacea (Boco), Commiphora africana (Coaf), Commiphora baluensis (Coba), Commiphora campestris (Coca), Commiphora riparia (Cori), Commiphora schimperi (Cosc), Dobera glabra (Dogl), Dobera loranthifolius (Dola), Grewia bicolor (Grbi), Lannea stuhlmannii (Last), Lecaniodiscus fraxinifolius (Lefr), Maerua pubescence (Mapu), Prosopis julifora (Prju), Salvadora persica (Sape), Sterculia africana (Staf), Terminalia brownii (Tebr), Terminalia parvula (Tepa)* and *Terminalia spinosa (Tesp).*

4.4.3.3 CCA of tree species and soil data in wildlife conservation areas

The total variation (inertia) in conservation areas was 7.98, with explanatory variables accounting for 5.29 which was quite high and the unexplained variation accounting 2.69 ((table 4.9). The eigenvalues of the first four axes were generally high implying that the four axes were important in influencing tree species distribution pattern in conservation areas. However, the eigenvalue of the first axis was the highest which implied that the first axis represented the strongest and the most important gradient in explaining the influence of soil characteristics on tree species distribution pattern. The first CCA axis explained the highest fitted variation of 18.2% of the total variation in the data set, with the first three CCA axes explaining 51.8%. All the four axes had high species-environmental correlation values.

Monte Carlo permutation test on all the axes showed no significant influence of soil properties ($P > 0.05$) on the tree species distribution pattern in conservation areas. However, a significant influence of soil properties ($P < 0.05$) on the tree species distribution pattern was observed along the first CCA axis (table 4.9). Tests on individual variables indicated that bulk density, moisture, phosphorus, magnesium, calcium and CEC had a significant influence ($P < 0.05$) on tree species distribution pattern (table 4.10). The influence of potassium on the distribution of tree species was not significant ($P > 0.05$).

Table 4.9: Summary results of the first four CCA-axes of data in conservation areas. Sig. = Significant; Total variation = sum of all unconstrained eigenvalues.

Axes	1	2	3	4	Total variation
CCA-Eigen values	0.963	0.895	0.881	0.688	7.975
Explained variation (Cumulative %)	12.1	23.3	34.3	43.0	
Explained fitted variation (Cumulative %)	18.2	35.1	51.8	64.8	
Canonical correlation	0.997	0.985	0.991	0.919	
All unconstrained eigen values					7.975
All canonical eigen values					5.29
Monte Carlo Permutation test	F-ratio	P-value	Conclusion		
CCA Axis 1	0.8	0.024	Significant		
All CCA Axes	1.1	0.280	Not sig.		

Table 4.9: Monte Carlo Permutation test results for significance of soil variables from conservation areas.

Variable	Variance	F-ratio	P-value	Conclusion
Moisture	0.142	1.7	0.006	Significant
pH	0.105	1.2	0.206	Not significant
Bulk density	0.154	1.8	0.002	Significant
Nitrogen	0.121	1.4	0.162	Not significant
Phosphorus	0.135	1.6	0.018	Significant
Org. Carbon	0.114	1.3	0.216	Not significant
Magnesium	0.145	1.7	0.010	Significant
Potassium	0.123	1.4	0.066	Not significant
Calcium	0.126	1.5	0.036	Significant
CEC	0.133	1.5	0.014	Significant

Most of the variables in conservation areas were strongly correlated with CCA-axis 1 which was a nutrient rich gradient (table 4.11). The variables which were positively correlated with the first axis were phosphorus (CCA-axis 1, r = 0.651) and moisture (CCA-axis 1, r = 0.556) (table 4.11). The variables which were negatively correlated with CCA-axis 1 were nitrogen (CCA-axis 1, r = -0.546), organic carbon (CCA-axis 1, r = -0.446), magnesium (CCA-axis 1, r = -0.536), calcium (CCA-axis 1, r = -0.428), potassium (CCA-axis 2, r = -0.417) and CEC (CCA-axis 1, r = -0.463) (table 4.11).

Table 4.10: Correlation coefficients of soil properties with the ordination axes indicating their influence on the distribution of tree species in wildlife conservation areas. Shown in bold are the soil properties with strong correlation coefficients to each axis.

Variable	Axis 1	Axis 2	Axis 3
BD	-0.484	**0.693**	-0.082
Mois	**0.556**	-0.158	-0.320
pH	-0.176	**0.426**	-0.080
C	-0.446	-0.022	0.310
N	**-0.546**	0.019	0.108
P	**0.651**	0.222	-0.087
K	-0.417	**0.477**	0.343
Mg	**-0.536**	0.364	0.414
Ca	**-0.428**	0.380	0.397
CEC	**-0.463**	0.377	0.403

The tree species that were favoured by increasing moisture and increasing concentrations of phosphorus were mainly found inside the floodplain. Tree species such as *Phoenix reclinata,* *Celtis philipensis, Aliangium salviifolium, Drypetes natalensis, Ziziphus pubescence, Kigelia africana, Tapura fischeri, Blighia unijugata, Rinorea elleptica, Hunteria zeylanica, Acacia zanzibarica* and *Terminalia parvula* were found in areas that were not frequently flooded (figure 4.3). The tree species that would thrive well in areas that were frequently flooded were *Hyphaene compressa, Pavetta sphaerobotris, Cordia gotzei* and *Sorindeia madagascariensis.* On the other hand, *Salvadora persica, Dobera loranthifolius, Dobera glabra, Lecaniodiscus fraxinifolius, Acacia tortilis, Acacia elatior, Acacia robusta, Prosopis juliflora, Balanites pedicellaris, Grewia bicolor, Boscia coriacea* and *Maerua pubescence* were suited to areas with low phosphorus and low moisture, mainly outside the floodplain (figure 4.3). *Prosopis juliflora* and *Acacia elatior* were suited to extremely dry conditions with low moisture. These trees were also favoured by the variables that were negatively correlated with CCA-axis 1. Thus, the tree species which were negatively correlated with CCA-axis 1 grew in soils that were rich in nitrogen, organic carbon and available bases but had low phosphorus and moisture.

Bulk density (CCA-axis 2, $r = 0.693$) and pH (CCA-axis 2, $r = 0.426$) were positively correlated with axis 2. Bulk density was the most important soil characteristic along axis 2 as denoted by the high r value (table 4.11). CCA-axis 2 was therefore a soil compaction gradient in which bulk density increased as pH increased. The tree species that were strongly correlated with high pH and bulk density along CCA-axis 2 were *Prosopis juliflora* and *Vachellia elatior*, whereas those that were correlated with moderate pH and bulk density were *Grewia bicolor, Boscia coriacea, Maerua pubescence, Terminalia pervula* and *Acacia zanzibarica* (figure 4.3). The tree species that were strongly correlated with low pH and bulk density were *Tapura fischeri, Blighia unijugata, Rinorea elleptica, Hunteria zeylanica, Polysphaera multiflora, Pavetta sphaerobotris, Cordia gotzei, Sorindeia madagascariensis,* *Hyphaene compressa.* On the other hand, *Balanites pedicellaris, Acacia tortilis, Lecaniodiscus fraxinifolius, Salvadora persica, Dobera loranthifolius* and *Acacia robusta* were found in soils with moderate pH and bulk density (figure 4.3).

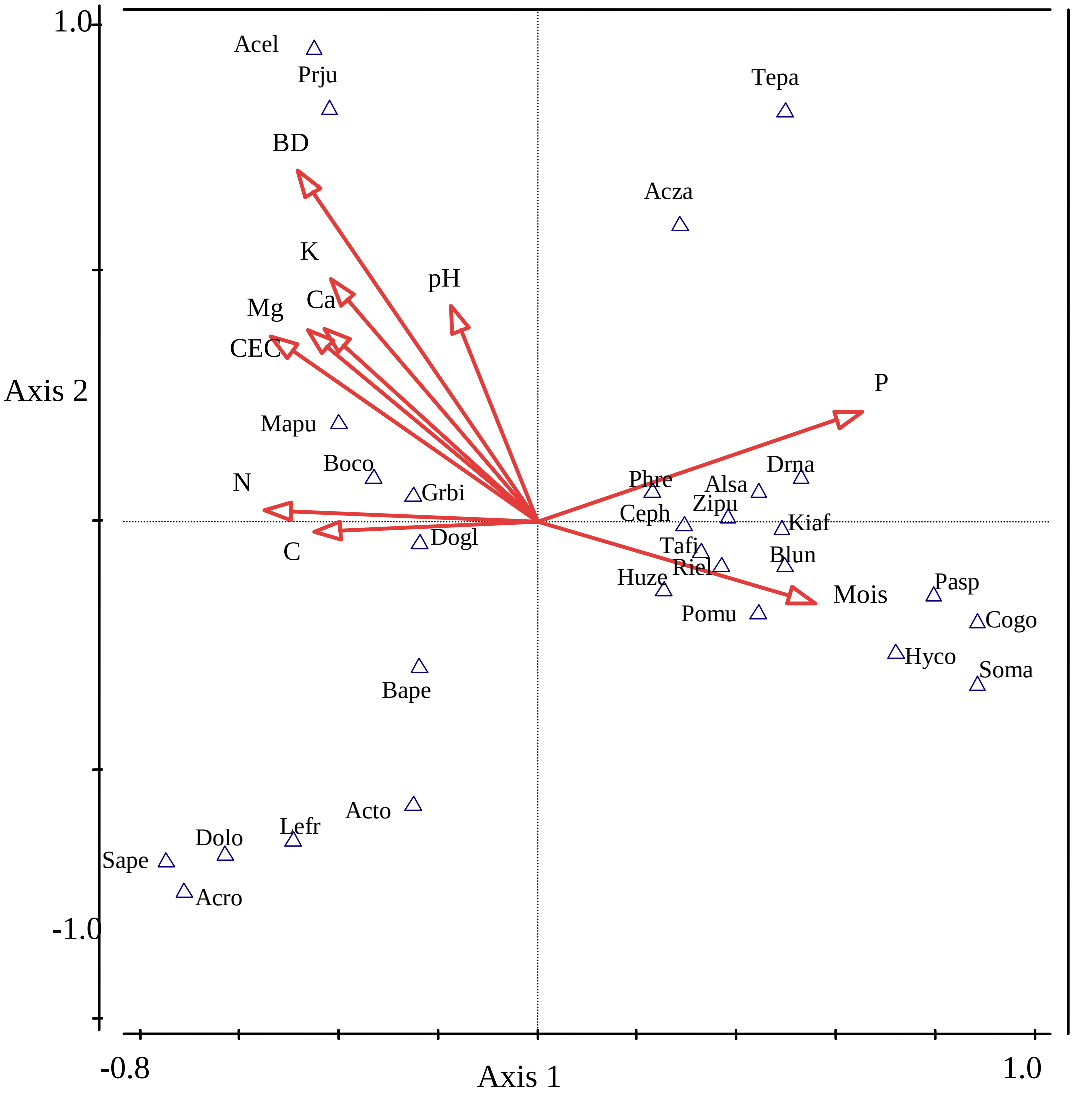

Figure 4.3**:** CCA biplot showing the influence of soil characteristics on tree species distribution patterns in wildlife conservation areas. The tree species are *Acacia elatior (Acel), Acacia robusta (Acro), Acacia tortilis (Acto), Acacia zanzibarica (Acza), Alangium salviifolium (Alsa), Balanites pedicellaris (Bape), Blighia unijugata (Blun), Boscia coriacea (Boco), Celtis philipensis (Ceph), Cordia gotzei (Cogo), Dobera glabra (Dogl), Dobera loranthifolius (Dolo), Drypetes natalensis (Drna), Grewia bicolor (Grbi), Hyphaene compressa (Hyco), Hunteria zeylanica (Huze), Kigelia africana (Kiaf), Lecaniodiscus fraxinifolius (Lefr), Maerua pubescence (Mapu), Pavetta sphaerobotris (Pasp), Phoenix reclinata (Phre), Polysphaera multiflora (Pomu), Prosopis juliflora (Prju), Rinorea elleptica (Riel), Salvadora persica (Sape), Sorindeia madagascariensis (Soma), Tapura fischeri (Tafi), Terminalia parvula (Tepa)* and *Ziziphus pubescence (Zipu).*

4.4.3.4 CCA of tree species and soil data from livestock grazing areas

The total variation (inertia) in livestock grazing areas was 6.36, with explanatory variables accounting for 3.02 and the unexplained variation accounting for 3.34 (table 4.12). The eigenvalue at the first axis was the highest which implied that this axis represented the strongest and the most important gradient in explaining the influence of soil characteristics on tree species distribution pattern. The first CCA axis explained the highest fitted variation of 21.5% of the total variation in the data set, with the first three CCA axes explaining 55.9%. The species-environmental correlation values were high for all the four axes.

The soil properties did not significantly influence the tree species distribution in grazing areas as indicated by the Monte Carlo permutation test on all CCA axes and on the first CCA axis (table 4.12). However, analysis of significance for individual variables indicated that moisture, phosphorus, magnesium, potassium, calcium and CEC had a significant influence ($P < 0.05$) on the tree species distribution in grazing areas (Table 4.13).

Table 4.11: Summary results of the first four CCA-axes of data from livestock grazing areas. Total variation = sum of all unconstrained eigenvalues.

Axes	1	2	3	4	Total variation
CCA-Eigen values	0.648	0.532	0.507	0.442	6.355
Explained variation (Cumulative %)	10.2	18.6	26.5	33.5	
Explained fitted variation (Cumulative %)	21.5	39.1	55.9	70.6	
Canonical correlation	0.945	0.921	0.872	0.921	
All unconstrained eigen values					6.355
All canonical eigen values					3.019
Monte Carlo Permutation test	F-ratio	P-value	Conclusion		
CCA Axis 1	1.4	0.540	Not significant		
All CCA Axes	1.1	0.226	Not significant		

Table 4.12: Monte Carlo Permutation test results for significance of soil variables from livestock grazing areas

Variable	Variance	F-ratio	P-value	Conclusion
Moisture	0.168	1.8	0.004	Significant
pH	0.152	1.6	0.134	Not significant
Bulk density	0.107	1.3	0.322	Not significant
Nitrogen	0.097	1.1	0.446	Not significant
Phosphorus	0.165	1.8	0.042	Significant
Org. Carbon	0.120	1.3	0.114	Not significant
Magnesium	0.148	1.6	0.046	Significant
Potassium	0.150	1.6	0.018	Significant
Calcium	0.148	1.6	0.022	Significant
CEC	0.154	1.7	0.012	Significant

Magnesium (CCA-axis 1, r = -633) and moisture (CCA-axis 1, r = -0.716) were strongly negatively correlated with the first species axis in livestock grazing areas (table 4.14). The tree species which were correlated with a high concentration of magnesium and moisture along axis 1 were *Excoecaria madagascariensis, Acacia elatior, Acacia zanzibarica, Prosopis juliflora, Acacia tortilis* and *Terminalia spinosa.* On the other hand, *Maerua pubescence, Grewia bicolor, Dobera glabra, Terminalia parvula, Terminalia brownii, Acacia nilotica, Acacia robusta, Salvadora persica, Diospyros abyssinica, Lanea stuhlmannii, Commiphora baluensis, Commiphora africana, Commiphora riparia, Commiphora campestris, Sterculia africana* and *Albizia anthelmintica* were correlated with low magnesium and moisture along CCA-axis 1. The first axis was therefore a magnesium soil saturation gradient and the plant species which were negatively correlated with this axis grew in soils with high moisture content and high concentration of magnesium salts.

Table 4.13: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species in livestock grazing areas. Shown in bold are the soil properties with strong correlation coefficients to each axis.

Variable	Axis 1	Axis 2	Axis 3
BD	0.096	**-0.549**	0.227
Mois	**-0.716**	0.269	0.282
pH	-0.447	**0.504**	-0.307
C	0.429	0.434	-0.149
N	0.046	0.272	-0.299
P	-0.114	**0.707**	-0.452
K	-0.381	**0.575**	-0.306
Mg	**-0.633**	0.406	0.039
Ca	-0.426	**0.561**	-0.267
CEC	-0.499	**0.543**	-0.219

Most of the variables were correlated strongly with axis 2, most of them positively. Bulk density was negatively correlated with the second axis (CCA-axis 2, r = -0.549), whereas phosphorus, potassium, pH, calcium, organic carbon and CEC were positively correlated with this axis (r = 0.707, 0.575, 0.504, 0.561, 0.434 and 0.543 respectively) (table 4.14). The second axis was therefore a soil nutrient saturation gradient where nutrients increased as bulk density decreased and vice versa. The tree species that were correlated with increasing soil nutrients and decreasing bulk density were *Prosopis juliflora, Acacia zanzibarica, Dobera glabra, Terminalia brownii, Acacia robusta, Salvadora persica, Acacia elatior, Excoecaria madagascariensis, Lannea stuhlmannii, Commiphora baluensis, Commiphora campestris* and *Sterculia africana.* The aforementioned tree species grew in soils with low bulk density and rich in nutrients. Other tree species such as *Acacia tortilis, Acacia nilotica, Maerua pubescence, Grewia bicolor, Terminalia parvula, Diospyros abyssinica, Commiphora africana, Commiphora riparia, Terminalia spinosa* and *Albizia anthelmintica* were found in soils with high bulk density and low nutrients.

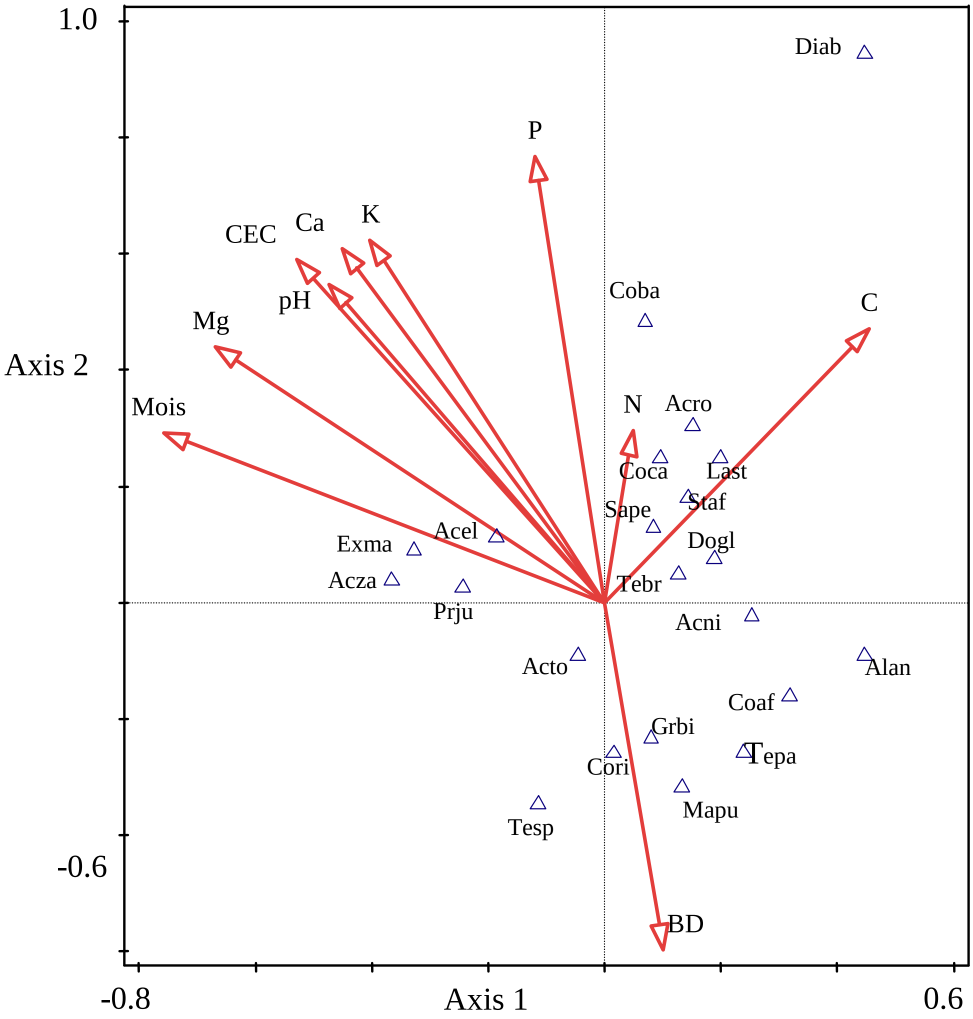

Figure 4.4: CCA biplot showing the influence of soil characteristics on tree species distribution patterns in livestock grazing areas. The tree species are *Acacia elatior (Acel), Acacia nilotica (Acni), Acacia robusta (Acro), Acacia tortilis (Acto), Acacia zanzibarica (Acza), Albizia anthelmintica (Alan), Commiphora africana (Coaf), Commiphora baluensis (Coba), Commiphora campestris (Coca), Commiphora riparia (Cori), Diospyros abyssinica (Diab), Dobera glabra (Dogl), Excoecaria madagascariensis (Exma), Grewia bicolor (Grbi), Lanea stuhlmannii (Last), Maerua pubescence (Mapu), Prosopis juliflora (Prju), Salvadora persica (Sape), Sterculia africana (Staf), Terminalia brownii (Tebr), Terminalia parvula (Tepa)* and *Terminalia spinosa (Tesp)*

4.4.3.5 CCA of tree species and soil data from irrigated agricultural areas

The CCA ordination of species data from irrigated agricultural areas showed that the total variation (inertia) was 7.56, with explanatory variables accounting for 4.30 and the unexplained variation accounting for 3.26 (table 4.15). The eigenvalue of the first axis was the highest which implied that this axis represented the strongest and the most important gradient in the influence of soil characteristics on tree species distribution pattern in irrigated agricultural areas. The first CCA axis explained the highest fitted variation of 19.7% of the total variation in the data set, with the first three CCA axes explaining 53.7%. Monte Carlo permutation test on all CCA axes and on the first CCA axis showed that the soil variables had insignificant influence ($P > 0.05$) on the tree species distribution pattern in irrigated agricultural areas (table 4.15). However, pH and organic carbon had a significant influence ($P < 0.05$) on the tree species distribution pattern in irrigated agricultural areas (Table 4.16), but along the first and third axes respectively (table 4.17).

Table 4.14: Summary results of the first four CCA-axes of data from irrigated agricultural areas. Total variation = sum of all unconstrained eigenvalues.

Axes	1	2	3	4	Total variation
CCA-Eigen values	0.848	0.760	0.701	0.504	7.555
Explained variation (Cumulative %)	11.2	21.3	30.6	37.2	
Explained fitted variation (Cumulative %)	19.7	37.4	53.7	65.4	
Canonical correlation	0.989	0.947	0.965	0.872	
All unconstrained eigen values					7.555
All canonical eigen values					4.299
Monte Carlo Permutation test	F-ratio	P-value	Conclusion		
CCA Axis 1	1.0	0.434	Not significant		
All CCA Axes	1.1	0.260	Not significant		

Table 4.15: Monte Carlo Permutation test results for significance of soil variables from irrigated agricultural areas

Variable	Variance	F-ratio	P-value	Conclusion
Moisture	0.100	1.1	0.464	Not significant
pH	0.180	1.9	0.004	Significant
Bulk density	0.088	0.9	0.664	Not significant
Nitrogen	0.109	1.1	0.308	Not significant
Phosphorus	0.119	1.3	0.226	Not significant
Org. Carbon	0.135	1.4	0.032	Significant
Magnesium	0.110	1.2	0.336	Not significant
Potassium	0.123	1.3	0.246	Not significant
Calcium	0.128	1.3	0.214	Not significant
CEC	0.122	1.3	0.228	Not significant

Most of the variables in irrigated agricultural areas were strongly correlated with the first axis (Table 4.17)**.** The first CCA-axis was characterized by phosphorus, bases, pH, CEC and was therefore a nutrient saturation gradient. Phosphorus (CCA-axis 1, r = -0.531), pH (CCA-axis 1, r = -0.852), potassium (CCA-axis 1, r = -0.447), magnesium (CCA-axis 1, r = -0.478), calcium (CCA-axis 1, r = -0.501), and CEC (CCA-axis 1, r = -0.479) were negatively correlated with the first axis (table 4.17). The tree species that were correlated with increasing concentrations of these variables were *Acacia robusta, Acacia zanzibarica, Acacia nilotica, Prosopis juliflora, Tamarindus indica, Eucalyptus saligna, Lecaniodiscus fraxinifolius, Ficus sycomorus, Mangifera indica, Azadirachta indica, Musa paradisiaca* and *Excoeraria madagascariensis* (figure 4.5). These species were abundant where the soils had a high concentration phosphorus, bases and therefore high pH and CEC. *Grewia bicolor, Boscia coriacea* and *Commiphora riparia, Commiphora schimperi, Maerua pubescence, Acacia tortilis* and *Salvadora persica* were correlated with decreasing phosphorus, bases, pH and CEC along CCA-axis 1 and grew in acidic soils. Nitrogen (CCA-axis 3, r = 0.481), organic carbon (CCA-axis 3, r = 0.469), moisture (CCA-axis 3, r = 0.425) and bulk density (CCA-axis 3, r = -0.386) were strongly correlated with the third axis (table 4.17). However, bulk density was also correlated with CCA-axis 1 (CCA-axis 1, r = -0.302), whereas moisture and organic carbon were also correlated with CCA-axis 2 (r = -0.303 and 0.328 respectively). The tree species which were correlated with high bulk density along the first axis were *Acacia robusta, Acacia zanzibarica, Acacia nilotica, Prosopis juliflora, Tamarindus indica, Eucalyptus saligna, Lecaniodiscus fraxinifolius, Ficus sycomorus, Mangifera indica, Azadirachta indica* (figure 4.5). Those that were correlated with low bulk density were *Grewia bicolor, Boscia coriacea, Commiphora riparia, Commiphora schimperi, Maerua pubescence, Acacia tortilis* and *Salvadora persica.*

Table 4.16: Correlation coefficients of soil properties with ordination axes indicating their influence on the distribution of tree species in irrigated agricultural areas. Shown in bold are the soil properties with strong correlation coefficients to each axis.

Variable	Axis 1	Axis 2	Axis 3
BD	-0.302	0.250	-0.386
Mois	-0.270	-0.303	**0.425**
pH	**-0.852**	-0.115	-0.341
C	-0.367	0.328	**0.469**
N	-0.052	0.190	**0.481**
P	**-0.531**	0.269	0.159
K	**-0.447**	-0.297	-0.049
Mg	**-0.478**	-0.274	0.052
Ca	**-0.501**	-0.313	-0.014
CEC	**-0.479**	-0.306	0.002

The tree species that were correlated with high moisture and low carbon along CCA-axis 2 grew in soils that had high moisture and low carbon. These included *Prosopis juliflora, Acacia tortilis, Acacia nilotica, Acacia zanzibarica, Maerua pubescence, Eucalyptus saligna, Commiphora schimperi, Salvadora persica and Tamarinda indica.* Other tree species such *Mangifera indica, Ficus sycomorus, lecaniodiscus fraxinifolius, Acacia robusta, Azadirachta indica, Grewia bicolor, Commiphora riperia, Boscia coriacea* were abundant in soils that had relatively low moisture but high organic carbon.

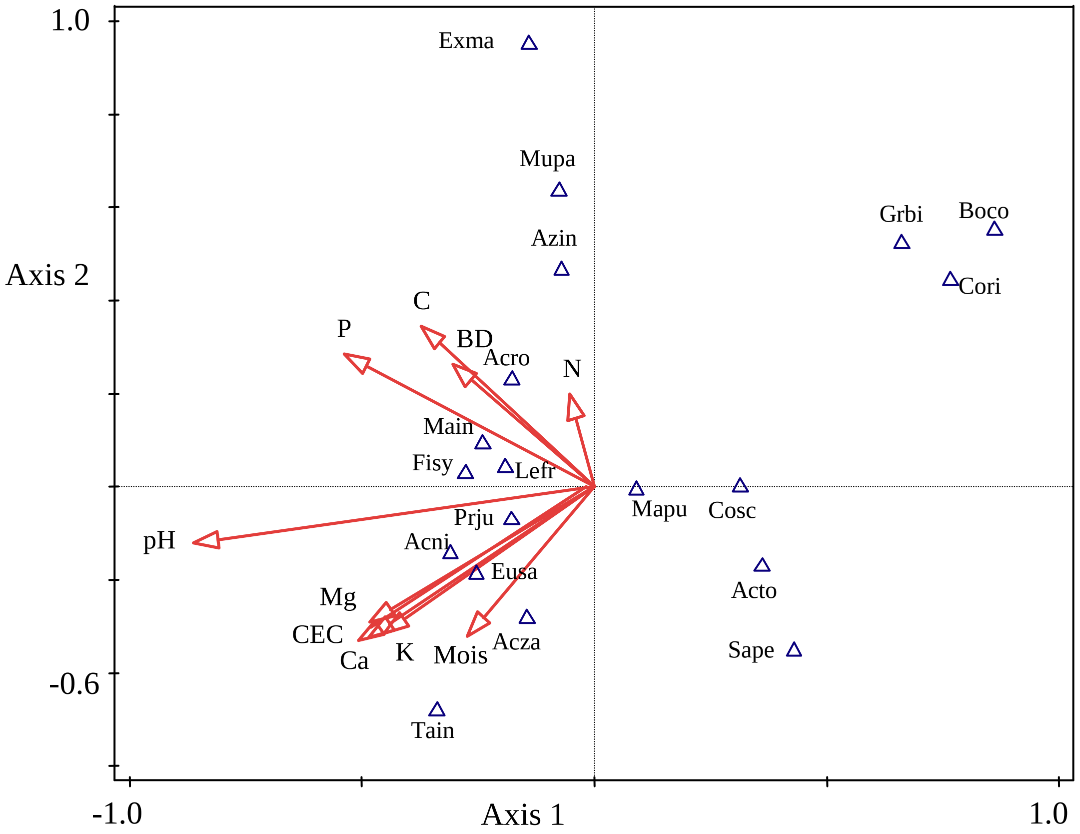

Figure 4.5: CCA biplot showing the influence of soil characteristics on tree species distribution patterns in irrigated agricultural areas. The tree species are *Acacia nilotica (Acni), Acacia robusta (Acro), Acacia tortilis (Acto), Acacia zanzibarica (Acza), Azadirachta indica (Azin), Boscia coriacea (Boco), Commiphora riparia (Cori), Commiphora schimperi (Cosc), Eucalyptus saligna (Eusa), Excoeraria madagascariensis (Exma), Ficus sycomorus (Fisy), Grewia bicolor (Grbi), Lecaniodiscus fraxinifolius (Lefr), Maerua pubescence (Mapu), Mangifera indica (Main), Musa paradisiaca (Mupa), Prosopis juliflora (Prju), Salvadora persica (Sape)* and *Tamarindus indica (Tain).*

4.5 Discussion

4.5.1 Variation in soil characteristics

This study has shown that most of the variables (moisture, pH, organic carbon, nitrogen, phosphorus, potassium, magnesium, calcium and CEC) had mean values that were higher inside the floodplain compared to outside the floodplain (table 4.1). However, only the mean differences of moisture, pH, phosphorus, magnesium and calcium were significantly higher ($P < 0.05$). CEC was marginally significant ($0.05 < P \leq 0.1$) inside compared to outside the floodplain. Bulk density is the only variable which was significantly higher ($P < 0.05$) outside the floodplain. On the other hand, most of the variables (phosphorus, pH, moisture, potassium, magnesium, calcium and CEC) were higher in areas where irrigated agriculture is practiced than in livestock grazing and wildlife conservation areas. However, only phosphorus showed a significant difference ($P < 0.05$) (table 4.2).

The increased water and nutrients inside the floodplain can be attributed to the semi-annual floods that occur in upper Tana River County in the months of May and November/December. The floods are in response to the long and short rainy seasons that occur in the river catchment area located in Mount Kenya and the Aberdare Range (Maingi, 2006). All the irrigated agricultural areas except those in Bura and Hola irrigation schemes were inside the floodplain. This explains why most of the variables were higher in irrigated agricultural areas, just like inside the floodplain. According to Howell & Benson (2000), floods provide water and nutrients that support plants regeneration and growth. Indeed, a research done by Mworia *et al*. (2011) in upper Tana River County attributed the high regeneration of *Prosopis juliflora* inside the floodplain to availability of more resources (nutrients and water).

Seasonal floods contribute additional moisture and nutrients in the floodplain, hence these resources were higher in the floodplain and in irrigated agricultural areas. Soil moisture contributes significantly in determining the performance of different plants since it permits access to dissolved nutrients for plant uptake. According to McKenzie *et al.* (2004), most nutrients exist in ionic form and soils that have more cations are more fertile. On the other hand, CEC is a measure of the soil's ability to hold positively charged ions (cations) such as hydrogen, magnesium, potassium and calcium. CEC influences soil structural stability, nutrient availability, soil pH and the soil's reaction to fertilizers and other ameliorants (Hazleton & Murphy, 2007). It is thus related to cations and hence to nutrient availability, implying that in fertile soils the concentration of cations is high.

This study has also shown that in grazing areas, bulk density was the only soil variable which was highest and also significantly higher ($P < 0.05$) compared to its value in other land use types. High bulk density affects root growth, aeration and water infiltration (Mworia *et al.* 2009), which can negatively impact plant growth. On the other hand, moisture, potassium, magnesium, calcium and CEC were lowest in grazing areas compared to other land use types (table 4.2). This implies that livestock grazing increased soil bulk density through trampling but reduced moisture and cations. A study by Tate *et al.* (2004) in California showed that bulk densities were higher in grazed areas than in non-grazed areas. Another study carried out by Mworia *et al.* (2009) in Kajiado, Kenya showed that the bulk density of grazed plots was significantly high compared to that of ungrazed plots. In Northern Loess Plateau of China, both livestock grazing and trampling by humans and livestock increased bulk density and lowered the soil water content in a semi-arid grassland (Zhou *et al.* 2010). A more recent research by Pulido *et al.* (2016) in the rangelands of SW Spain found that bulk density was high in enclosures that had high animal stocking rates. Kamau (2004) carried out a research in Mbeere District in Kenya and found that grazed plots had high soil bulk density and lower moisture, organic matter and total nitrogen compared to enclosed plots which were not grazed. The current study concurs with the findings of the above researchers that livestock grazing increases soil bulk density. In addition, moisture, potassium, magnesium, calcium and CEC were lowest in livestock grazing areas, which imply low soil fertility since cations are indicators of soil fertility.

4.5.2 Influence of soil characteristics on tree species distribution

Canonical correspondence analysis indicated that the explanatory variables accounted for more outside the floodplain (42.9%) compared to inside the floodplain (36.8%), suggesting that there was more unexplained variation in the floodplain than outside the floodplain. On the other hand, the unexplained variation was highest in livestock grazing areas followed closely by irrigated agricultural areas. The high unexplained variation inside the floodplain and in livestock and irrigated agricultural areas suggests that other factors besides the selected soil characteristics influenced the distribution of tree species. These factors include anthropogenic disturbances due to livestock grazing, clearance of land and intense crop farming activities in irrigated agricultural areas. Mligo *et al.* (2009) found that besides soil nutrients, disturbance also influenced the distribution of plants in the coastal forests of Tanzania. Stevens and Hornung (1990) pointed out that land clearance & leaching through erosion can lead to loss of cations such as magnesium and calcium. These mineral ions have been found to influence plant abundance and distribution (Mligo, 2016; Adel *et al.* 2017) and their loss through disturbance can affect plant species distribution. In conservation areas, the explanatory variables accounted for 66.3% of the total variation which was quite high. This suggests that soil properties were the major factors that influenced tree species distribution in wildlife conservation areas. This was not surprising since there was minimal disturbance in conservation areas.

The species-environmental correlations at the first four axes were high both in and outside the floodplain and also in wildlife conservation, livestock grazing and irrigated agricultural areas. Although this was not unusual since in CCA the relationship between species and the environment is always maximized, it pointed to possible significance of the soil variables on the abundance and distribution of the tree species. The high eigenvalues and cumulative percentages of variance showed that the soil variables assessed influenced the distribution pattern of tree species. Monte Carlo permutation test revealed the soil variables which significantly influenced tree species distribution, both in and outside the floodplain and in the three main land use types. The post-CCA test showed that the ordination results were not obtained by chance so the soil properties indeed had an influence on the distribution of the trees.

There were different levels of interactions; between the individual tree species, between the soil properties and between the tree species and the soil properties, all of which defined the behaviour of the canonical axes in ordination space. Some tree species were correlated with high concentrations of soil mineral elements while others were correlated with low levels. Tree species abundance and distribution varied in response to soil nutrient saturation gradients in the floodplain and outside the floodplain in the three land use types. According to Munishi *et al.* (2007), soil moisture, soil properties, biotic components and landscape characteristics can all influence vegetation community structure. Some studies (Gholinejad *et al.* 2012 and Ebrahimi *et al.* 2015) have shown that factors related to topography such as slope and altitude influenced the distribution of plants. Biotic components such as land clearance and charcoal burning have also been shown to influence the distribution pattern of plant species (e.g. Mligo, 2016). Although landscape characteristics and biotic components may have influenced the distribution of tree species in the current study, emphasis was put on the measured soil properties.

Some tree species grew in soils with high concentrations of cations (potassium, calcium, magnesium) and the main nutrients (phosphorus or nitrogen) and others in soils with low concentrations. Bulk density (soil compaction) and organic carbon as indicators of soil physical structure also affected distribution and composition of tree species. Both in and outside the floodplain, bulk density and cations (calcium, magnesium, potassium) significantly influenced the distribution of tree species. However, moisture, pH, phosphorus, nitrogen and organic carbon also influenced the distribution of tree species outside the floodplain significantly. In wildlife conservation and livestock grazing areas, moisture, phosphorus and cations influenced tree species distribution significantly. However, in irrigated agricultural areas only organic carbon and pH had a significant influence on tree species distribution. In a number of related studies, soil properties have been found to influence the abundance and distribution of plant species (Graham *et al*. 2005; Robert *et al*. (2006); Udoh *et al.* 2007; Mligo *et al.* 2009 ; Zare *et al*. 2011; Iwara *et al.* 2011 ; Azarnivand *et al.* 2014). Iwara *et al.* 2011 found that CEC, phosphorus, nitrogen and silt influenced the distribution of woody species in South-Southern Nigeria. Another study by Mligo (2016) assessed the influence of soil chemical properties on plant species distribution pattern in Zaraninge forest in Tanzania. The results indicated that calcium, magnesium and phosphorus significantly influenced the distribution pattern of plant species in this forest. A more recent study by Adel *et al. (*2017) in northern Iran found that nitrogen, phosphorus, organic carbon, pH, potassium, magnesium and calcium were among the most important soil properties that influenced the growth and distribution of plant communities. In this study, bulk density, moisture, phosphorus, pH, CEC and cations (potassium, calcium, magnesium) played an important role in determining the distribution and composition of tree species. Disturbances caused by livestock grazing and crop farming may also have influenced the distribution of trees. This is because in conserved areas where disturbance was minimal, a large variation was accounted for by the measured soil variables compared to livestock grazing and irrigated agricultural areas.

Soils that retain more cations such as magnesium, potassium and calcium also have large quantities of negatively charged ions and are therefore more fertile (Mckenzie *et al.* 2004). Thus, based on the findings of this study, the soils in the floodplain were more fertile compared to those outside the floodplain. Indeed, most of the tree species were correlated with high concentrations of cations, phosphorus and moisture which were significantly higher inside the floodplain. Plants require nutrients for growth and hence soils with sufficient nutrients promote their growth. Indeed, increasing the amounts of soil nutrients has been shown to promote the growth of different plants (e.g. Davis *et al.* 2000; Marcia & Anderson 2004; Owens *et al.* 2007). On the other hand, moisture plays an important part in determining the performance of different plant species since it permits access to dissolved nutrients for plant uptake. This explains why moisture had a significant influence on tree species distribution outside the floodplain where moisture was significantly less compared to inside the floodplain. Moisture also significantly influenced tree species distribution in wildlife conservation and livestock grazing areas which had less moisture compared to irrigated agricultural areas.

The invasive plant *Prosopis juliflora* was found inside and outside the floodplain in all the three land use types. This invader was found in locations with diverse soil conditions implying that the factors that favoured its distribution and abundance were quite varied. High concentrations of potassium, magnesium and calcium, pH, bulk density, moisture, phosphorus, nitrogen, CEC, seemed to be suitable conditions for *P. juliflora.* However, it also thrived well in conditions of low moisture, CEC, phosphorus, nitrogen, organic carbon and low concentrations of potassium, magnesium and calcium. Invasive plants like *P. juliflora* are known to be more competitive for resources compared to indigenous plants and thus can displace them (Tilman, 1997; Davis *et al.* 2000; kolb *et al.* 2002; Muturi *et al.* 2009; Getachew *et al.* 2012). Consequently, the indigenous tree species that were close to *P. juliflora* were considered to be under threat.

4.6 Conclusion

This study determined the variation in soil characteristics and their influence on tree species distribution inside and outside the floodplain among the main land use types (wildlife conservation, livestock grazing and irrigated agriculture) in upper Tana River. The results showed that there was variation in the soil characteristics inside and outside the floodplain and among the main land use types. In addition, the soil characteristics influenced the distribution of tree species in Tana River County, some of them significantly.

Moisture, pH, phosphorus, magnesium, calcium and CEC were significantly higher inside the floodplain as opposed to bulk density which was significantly higher outside the floodplain. The concentration of phosphorus was higher in irrigated agricultural areas than in conservation areas, and that of nitrogen higher in conservation areas than in irrigated agricultural areas. Bulk density was higher in livestock grazing areas compared to irrigated agricultural and wildlife conservation areas.

CCA showed that more variables significantly influenced the distribution pattern of tree species outside the floodplain compared to inside the floodplain. However, the soil variables that significantly influenced the distribution of tree species both inside and outside the floodplain were bulk density, potassium, calcium and CEC. Moisture, phosphorus, magnesium, calcium, potassium and CEC significantly influenced the distribution pattern of tree species both in conservation and grazing areas. In addition, bulk density also significantly influenced tree distribution in conservation areas. However, only pH and organic carbon influenced the distribution of tree species significantly in irrigated agricultural areas.

The abundance of *Prosopis juliflora* invader varied inside and outside the floodplain among the different land use types. Its distribution was influenced by varied soil conditions, implying that this invasive plant could thrive well in different soil conditions. This implied that the indigenous plants were threatened with displacement over time since invasive plants are more competitive for resources that are necessary for growth.

CHAPTER FIVE: EFFECTS OF DEFOLIATION AND CULTIVATION ON THE GROWTH PERFORMANCE OF *A. tortilis* AND *P. juliflora*

5.1 Introduction

The density of woody plants in savanna ecosystems has progressively increased due to overuse and degradation of the herbaceous layer by grazers (Chirara & Dijkman, 2002). To support the ever increasing human population in savanna ecosystems, more land has been cleared for cultivation and the remaining land is under pressure to support livestock. Moreover, rangelands in savanna ecosystems are increasingly being invaded by alien invasive plant species (Pasiecznik, 1999), which can displace indigenous plant species because they are more competitive for resources (Tilman, 1997; Davis *et al.* 2000; Van Auken, 2000; Kolb *et al.* 2002). The increasing pressure on land and invasion by alien species, can affect vegetation dynamics in savanna ecosystems.

According to the two layer model of Walter (1971), grasses and trees are superior competitors for moisture on topsoil and subsoil layers respectively (Walker *et al*. 1981; *Sala et al.* 1989). Field studies have been conducted in savanna ecosystems of Africa on competition involving trees and grasses for soil moisture (Smith & Goodman, 1986; Skarpe, 1990). These studies have concentrated on adult trees more than on woody species seedlings. However, woody species seedlings and established grasses share resources at the same level (Chirara *et al*. 2002), inevitably competing for the available resources. Since the establishment of seedlings is an important life history stage for populations to continue existing and expanding (Goldberg, 1990), field and greenhouse experiments have been carried out to help understand the effect of grazing on emergence, survival or growth of woody species seedlings. Such studies have used herbaceous defoliation to simulate grazing (Brown *et al.* 1998; Chirara *et al.* 1999; Chirara & Dijkman, 2002). However, more studies on woody seedling establishment are necessary in savanna ecosystems in the light of changing land use practices, increasing woody species invasion and climate change.

Climatic variability is manifested in cyclic droughts and floods that can have devastating effects on vegetation dynamics. Hence there is need to study vegetation dynamics in Tana River County, where these events are common. There has been increasing grazing intensity and cultivation to support the ever rising human population. The density of *Prosopis juliflora* has also been rising since its introduction in the 1980s, especially in the irrigation schemes and the floodplain. On the other hand, *Acacia tortilis* is an important resource for nomadic pastoralists (Andersen *et al.* 2014) since the pods are food for livestock during the drought periods. Part of the community (Somali, Orma and Wardei) practices pastoralism while the dominant tribe in this region (the Pokomo) practices flood recession agriculture and fishing to support their livelihoods. Pastoralism mainly occurs outside the floodplain and cultivation takes place mainly inside the floodplain.

Soil nutrients and water are among the environmental factors that are necessary for germination, survival and growth of plants. However, in arid and semi-arid lands, water is the single most important factor limiting tree establishment (Kramer, 1980; Otieno *et al.* 2001). Water stress influences a wide variety of morphological and physiological processes in plants such as leaf expansion, stomatal opening, membrane functioning and photosynthetic carbon assimilation and partitioning (Otieno *et al.* 2001). For example, *Acacia tortilis* responded differently to water stress compared to *Acacia xanthophloea*, which enables the former species to survive in dry regions (Otieno *et al*. 2001). Felker *et al.* 1983 found that *Prosopis* species were highly efficient in water usage because they have a deep taproot that enables them to reach deepground water. Moreover, they are fast growing and tolerant to arid conditions and saline soils (Pasiecznik *et al*. 2001), making them survive and perform better than plants with short and fibrous roots.

The seedling establishment stage is very important in the life-history of a tree (Sankaran *et al.* (2004). The stage is more important in the dry areas, where the existence of woody species depends on their ability to germinate and survive after periods of drought (Breshears & Barnes, 1999). The early stages of growth of *Prosopis juliflora* and indigenous woody plants have not been studied in Tana River County in the light of climate variability and increased intensity of grazing and crop farming. Some of the effects of climate variability include prolonged droughts and changed flood regimes, which in turn affect nutrient availability and moisture content (Chapter 4 of this study). The aim of this part of the study was to determine the emergence, survival and growth of *Prosopis juliflora* (an invasive species) and *Acacia tortilis* (an indigenous species) inside and outside the floodplain under different defoliation regimes. The defoliation regimes were used to simulate the effects of different grazing intensities and cultivation.

5.2 Objectives

The main objective of the field experiment was to determine the effects of herbaceous defoliation and cultivation on emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* seedlings on and off the floodplain. The specific objectives were:

- To determine the emergence and survival of *Acacia tortilis and Prosopis juliflora* seedlings under different defoliation regimes inside and outside the Tana River floodplain

- To determine the shoot height, taproot length and biomass of *Acacia tortilis and Prosopis juliflora* seedlings under different defoliation regimes inside and outside the Tana River floodplain

5.3 Materials and methods

5.3.1 Study site

The field experiment was carried out at Hola division in Tana River County, Kenya. Two sites were selected, one inside the floodplain (01^{o}29′11.4″S, 040^{o}01′59.0″E) and the other outside the floodplain (01^{o}29′09.8″S, 040^{o}01′56.0″E). The selected sites were 15m x 15m and fenced off to avoid external interference by large grazing herbivores such as camels, cattle, goats, sheep and large wild herbivores. Within the enclosures, 1m x 1m plots were measured and different levels of herbaceous vegetation defoliation were used to simulate a range of grazing intensities.

5.3.2 Experimental design

The herbaceous layer was manipulated as indicated below;

A. Not defoliated

B. Moderately defoliated (cut at 5cm height)

C. Heavily defoliated (cut at 2cm height)

D. Totally removed and bare soil dug to a depth of 30 cm to simulate cultivated land.

A total of 36 plots were used and the experimental design was randomized complete block with subsampling. The experimental layout was as illustrated below, with half a meter left between the blocks and between the plots;

Block 1		Block 2		Block 3
Aa Ab Ac	+	Ba Bb Bc	+	Ca Cb Cc
Ba Bb Bc		Da Db Dc		Aa Ab Ac
Ca Cb Cc		Aa Ab Ac		Da Db Dc
Da Db Dc		Ca Cb Cc		Ba Bb Bc

Where;

Total number of blocks = 3 (number of replicates)

Treatments = 4 (A, B, C and D) = Different defoliation regimes

Subsamples = 4 (a, b, ca, cb) Where;

Subsample a = 12 seeds of *Acacia tortilis* in a plot

Subsample b = 12 seeds *Prosopis juliflora* in a plot

Subsample c = Consisted of six seeds of *Acacia tortilis* (subsample ca) and six seeds of *Prosopis juliflora* (subsample cb) planted alternately in the same plot. The 12 seeds of the different subsamples per plot were as illustrated below:

Acacia tortilis	*Prosopis juliflora*	Mixed seeds
a a a	b b b	ca cb ca
a a a	b b b	cb ca cb
a a a	b b b	ca cb ca
a a a	b b b	cb ca cb
Separate plot	Separate plot	Shared plot

Twelve seeds of each plant species or mixed seeds in the ratio 1:1 were planted in four rows at a depth of 1cm in each of the plots. The mixed seeds were planted alternately in the four rows. The replications of treatments were assigned at random to independent groups of experimental plots within the blocks. The seeds of *Prosopis juliflora* were obtained from the study area between September and October 2014 and those of *Acacia tortilis* from Kenya Agricultural Research Institute, Muguga. Scarification of *Prosopis juliflora* seeds was done using sulphuric acid (1N) for 40 minutes to initiate germination, which simulated the digestive process of herbivorous animals (Peláez *et al.* 1992). *Acacia tortilis* seeds were soaked in boiling water, left to cool and kept in the water for 24 hours before sowing to break dormancy (Azazi *et al.* 2013).

The seeds were planted at the beginning of the long rains in March 2015 so as to use natural precipitation. Cutting of herbaceous vegetation was done fortnightly without cutting the target seedlings and the vegetation taken away from the experimental plots. After the planting date, the number of seedlings of *Prosopis juliflora* and *Acacia tortilis* that emerged in the separate plots and in the shared plots were recorded weekly until no more seedlings emerged. The number of seedlings that survived was noted and recorded fortnightly. At the end of three months, the surviving seedlings were counted and recorded. Thereafter, all the plots inside and outside the floodplain were watered prior to uprooting the seedlings. This was necessary in order to soften the soil and avoid damaging the seedlings during the process of uprooting. Two of the surviving seedlings were selected randomly from plots that had more than two surviving seedlings and uprooted to be measured. In the few cases where the surviving seedling(s) was only one or two, growth measurements were taken for the seedling(s) available in the plot. The shoot height and taproot length of seedlings were measured and recorded. The seedlings were then placed into paper bags and weighed using an electronic weighing balance. The paper bags with the subsample seedlings from inside and outside the floodplain under the different defoliation treatments were labelled and allowed to dry naturally at room temperature (25°C). Weighing and recording was done weekly until the weight was constant, giving the biomass of the seedlings.

5.3.3 Data analysis

The emergence, survival and the seedling growth (shoot height, taproot length, and biomass) data were organized using Microsoft excel and subjected to a three-way ANOVA at 5% significance level. The three factors were location (inside and outside the floodplain), defoliation level and plant species. The means were compared using Fisher's protected least significant difference (LSD), also at 5% significant level. The plant species (subsamples) were *Acacia tortilis* (a) and *Prosopis juliflora* (b) planted in separate plots and *Acacia tortilis* (ca) and *Prosopis juliflora* (cb) planted alternately in the same plot in the ratio 1:1.

5.4 Results

5.4.1 Emergence of seedlings inside and outside the floodplain

All the three factors, location, subsample and treatment had highly significant effects on the emergence of seedlings. Thus, emergence differed between the floodplain and outside the floodplain ($F_{[1, 62]} = 308.68$, $P < 0.001$), the seeds of *Acacia tortilis* and *Prosopis juliflora* planted in separate plots and those planted together in the same plot (a, b, ca and cb subsamples), ($F_{[3, 62]} = 600.25$, $P < 0.001$) and between the different defoliation levels ($F_{[3, 62]} = 215.73$, $P < 0.001$). The interactions between location and subsample ($F_{[3, 62]} = 34.7$, $P < 0.001$) and between subsample and treatment ($F_{[9, 62]} = 5.61$, $P < 0.001$), had also highly significant effects on seedling emergence.

The mean number and standard errors of emerged seedlings per treatment inside and outside the floodplain is shown in figure 5.1. More seedlings of both *Acacia tortilis* and *Prosopis juliflora* emerged inside than outside the floodplain irrespective of whether the two species were planted in separate plots or in the same plot. Outside the floodplain *Acacia tortilis* seeds that were planted with *Prosopis juliflora* in the same plot failed to emerge in treatment A.

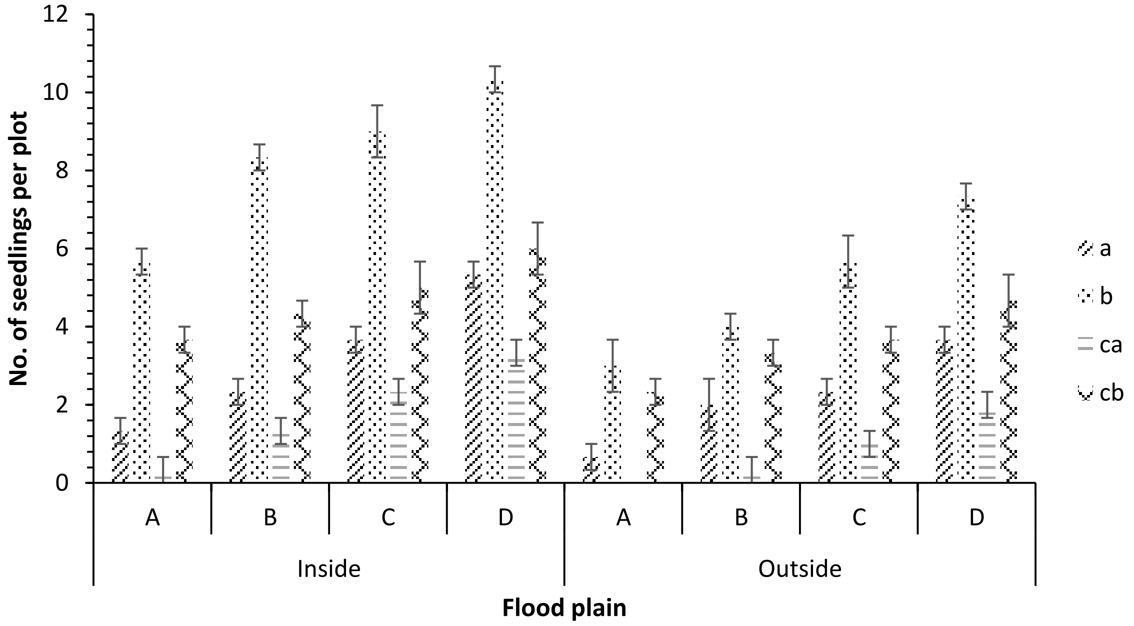

Figure 5.1: Mean number and standard errors of emerged seedlings per treatment inside and outside the floodplain.

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant interaction effect between location and subsample implied that the impact of location on emergence of seedlings depended on the species. Fisher's protected LSD test results (table 5.1) indicated that the number of seedlings that emerged inside the floodplain for all the species were significantly more than those that emerged outside the floodplain. Thus, emergence of seedlings was significantly higher inside the floodplain irrespective of whether the seeds were planted in separate plots (a and b) or together in the same plot (ca and cb). However, significantly more seedlings of subsample a (*Acacia tortilis*) emerged compared to subsample ca and significantly more of b (*Prosopis juliflora*) compared to cb. This implied that planting the seeds in the same plot significantly reduced emergence of both

Acacia tortilis and *Prosopis juliflora*. The number of seedlings of *Prosopis juliflora* that emerged was significantly more than those of *Acacia tortilis* both inside and outside the floodplain, whether planted in separate plots or in the same plot.

Table 5.1: Fisher's protected LSD test results for mean number of emerged seedlings in the location and subsample interactions. A significant difference in means is denoted by different superscripts.

Location x Subsamples	Mean
Inside floodplain x b	8.3^a
Outside floodplain x b	5.0^b
Inside floodplain x cb	4.8^b
Outside floodplain x cb	3.5^c
Inside floodplain x a	3.2^c
Outside floodplain x a	2.2^d
Inside floodplain x ca	1.8^d
Outside floodplain x ca	0.8^e

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1

The significant interaction effect between subsample and treatment implied that the impact of the defoliation treatment given on emergence of seedlings was dependent on the subsample. The results of Fisher's protected LSD test are shown in table 5.2. The number of seedlings of both *Acacia tortilis* and *Prosopis juliflora* that emerged increased as defoliation was intensified, being significantly fewer in treatment A (no defoliation) and significantly more in treatment D (total removal of herbaceous vegetation). This means that total removal of herbaceous vegetation and digging (simulating cultivation) enhanced the rate of emergence of both *Acacia tortilis* and *Prosopis juliflora* when planted in separate plots. Planting *Acacia tortilis* and *Prosopis juliflora* together in the same plot (subsamples ca and cb) significantly reduced seedling emergence of both species, but emergence still increased as defoliation was intensified.

Table 5.2: Fisher's protected LSD test results for mean number of emerged seedlings in the subsample and treatment interactions. The means with different superscripts are significantly different.

Sample.treatment	Mean
P. juliflora. D	8.8^{a}
P. juliflora. C	7.3^{b}
P. juliflora. B	6.0^{c}
P. juliflora. A	4.3^{ef}
A. tortilis. D	4.5^{e}
A. tortilis. C	3.0^{g}
A. tortilis.B	2.2^{hi}
A. tortilis. A	1.0^{j}
P. juliflora (a).D	5.3^{d}
P. juliflora (a).C	4.3^{ef}
P. juliflora (a). B	3.8^{f}
P. juliflora (a). A	3.0^{g}
A. tortilis (b). D	2.7^{gh}
A. tortilis (b). C	1.7^{i}
A. tortilis (b). B	0.8^{j}
A. tortilis (b). A	0.2^{k}

Key:
(a) = mixed with *A. tortilis* in the ratio 1:1
(b) = mixed with *P. juliflora* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

5.4.2 Survival of seedlings inside and outside the floodplain

Three-way analysis of variance on the survival data (number of surviving seedlings) indicated that all the three factors under consideration (location, subsample and treatment) had very significant effects on the survival of seedlings. Thus, survival of seedlings differed between inside and outside the floodplain ($F_{[1, 62]} = 253.92$, $P < 0.001$), the different subsamples (a, b, ca and cb) ($F_{[3, 62]} = 517.94$, $P < 0.001$) as well as between the different defoliation levels ($F_{[3, 62]} = 277.14$, $P < 0.001$. The interactions between location and subsample ($F_{[3, 62]} = 37.27$, $P < 0.001$), between treatment and location ($F_{[3, 62]} = 9.64$, $P < 0.001$) and between subsample and treatment ($F_{[9, 62]} = 7.08$, $P < 0.001$) all had very significant effects on survival of seedlings.

The mean survival and standard errors of seedlings per treatment inside and outside the floodplain is shown in figure 5.2. Generally, more seedlings of both *Acacia tortilis* and *Prosopis juliflora* survived inside than outside the floodplain, whether the two species were planted in separate plots or together in the same plot. However, *Acacia tortilis* seedlings failed to survive to the end of the three months under treatment A when planted singly and also when planted together with *Prosopis juliflora* in the same plot. Under treatment B, *Acacia tortilis* planted together with *Prosopis juliflora* in the same plot did not survive inside the floodplain. Outside the floodplain, *Acacia tortilis* seedlings failed to survive both when planted singly and when planted alternately with *Prosopis juliflora* in the same plot in both treatment A and treatment B. Hence, both planting the two species in close proximity and herbaceous vegetation reduced the survival of *Acacia tortilis* outside the floodplain.

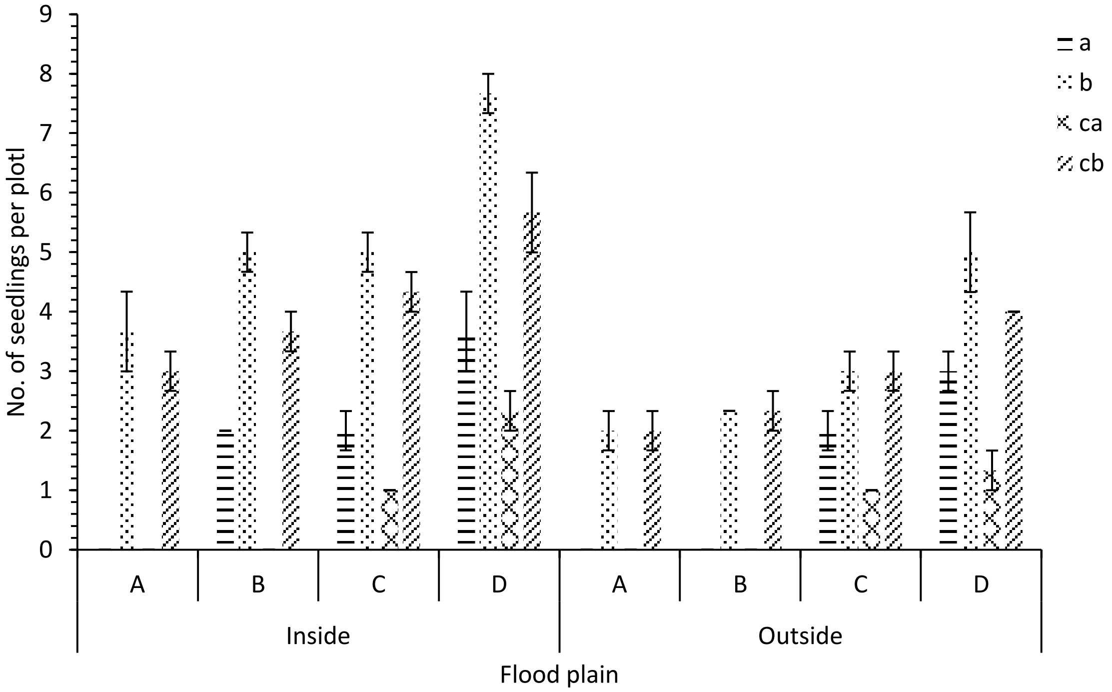

Figure 5.2: Mean survival and standard errors of subsample seedlings per treatment inside and outside the floodplain. Error bars are missing in cases where the standard error mean of the subsample was zero.

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant interaction effect between subsample and location implies that the impact of location on the survival of seedlings depended on the subsample. Fisher's protected LSD test results (table 5.3) indicated that the number of seedlings that survived inside the floodplain for all the subsamples were significantly more than those that survived outside the floodplain. Thus, survival of seedlings was significantly higher inside the floodplain for both the seeds that were planted in separate plots (subsamples a and b) and those planted together in the same plots (subsamples ca and cb). However, significantly more seedlings of subsamples a and b survived compared to subsamples ca and cb, implying that seedling survival was reduced by planting seeds of *Acacia tortilis* and *Prosopis juliflora* together in the same plots. The number of seedlings of *Prosopis juliflora* that survived was significantly more than those of *Acacia tortilis* both inside and outside the floodplain, whether planted singly in a plot or together with *Acacia tortilis* in the same plot.

Table 5.3: Fisher's protected LSD test results for mean survival of seedlings in the location and subsample interactions. The means with different superscripts are significantly different.

Location.subsample	Mean
Inside floodplain.b	5.3^{a}
Outside floodplain.b	3.1^{c}
Inside floodplain.cb	4.2^{b}
Outside floodplain.cb	2.8^{c}
Inside floodplain.a	1.9^{d}
Outside floodplain.a	1.3^{e}
Inside floodplain.ca	0.9^{f}
Outside floodplain.ca	0.6^{g}

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1

The significant interaction effect between treatment and location implied that the impact of a particular defoliation treatment on survival of seedlings depended upon the location. For all the treatments, significantly more seedlings survived inside the floodplain compared to outside the floodplain (table 5.4). Inside the floodplain, survival of seedlings increased as defoliation was intensified, being less in treatment A (herbaceous vegetation not defoliated). The number of seedlings that survived in treatment D was significantly more than those that survived in the other defoliation treatments, implying that total removal of herbaceous vegetation and digging (cultivation) enhanced survival of seedlings. Survival of seedlings outside the floodplain also increased as defoliation was intensified except that there was no significant difference in seedling survival between treatments A and B.

Table 5.4: Fisher's protected LSD test results for mean survival of seedlings in the treatment and location interactions. The means with different superscripts are significantly different.

Treatment.location	Mean
D.Inside floodplain	4.8^{a}
D.Outside floodplain	3.3^{b}
C.Inside floodplain	3.1^{b}
C.Outside floodplain	2.3^{d}
B.Inside floodplain	2.8^{c}
B.Outside floodplain	1.3^{f}
A.Inside floodplain	1.7^{e}
A.Outside floodplain	1.0^{f}

Key:
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

There was also a significant interaction effect between subsample and treatment, which implied that the impact of a given defoliation treatment on survival of seedlings depended on the subsample. The results of Fisher's protected LSD test are shown in table 5.5. The number of seedlings of subsample b that survived increased as defoliation was intensified, but seedling survival in treatments B and C was not significantly different. The number of surviving seedlings of subsample a increased significantly as defoliation was intensified, but no seedlings survived in any plot under treatment A (herbaceous vegetation not defoliated). For both species, the number of seedlings that survived in treatment D was significantly more than those in the other treatments. This means that total removal of herbaceous vegetation and digging (simulating cultivation) enhanced the survival of both *Acacia tortilis* and *Prosopis juliflora* when planted in separate plots. Planting *Acacia tortilis* and *Prosopis juliflora* alternately in the same plot (ca and cb) reduced the survival of both species, but the survival also increased as defoliation was intensified. The reduction in survival of *Prosopis juliflora* seedlings compared to when seeds were planted in separate plots was significant where defoliation was moderate and in cultivated plots. However, for *Acacia tortilis* the reduction was significant in all the treatments where seedlings had survived, i.e., in treatments C and D. The number of seedlings of *Prosopis juliflora* that survived was significantly more than those of *Acacia tortilis*, whether planted in separate plots or together in the same plots.

Table 5.5: Fisher's protected LSD test results for mean survival of seedlings in the subsample and treatment interactions. Different superscripts denote means with a significant difference.

Subsample.treatment	Mean
P. juliflora. D	6.3^{a}
P. juliflora. C	4.0^{c}
P. juliflora. B	3.7^{cd}
P. juliflora.A	2.8^{fg}
A. tortilis. D	3.3^{de}
A. tortilis. C	2.0^{h}
A. tortilis. B	1.2^{i}
P. juliflora (a). D	4.8^{b}
P. juliflora (a). C	3.7^{cd}
P. juliflora (a). B	3.0^{ef}
P. juliflora (a). A	2.5^{g}
A. tortilis (b). D	1.8^{h}
A. tortilis (b). C	1.0^{i}

Key:
(a) = mixed with *A. tortilis* in the ratio 1:1
(b) = mixed with *P. juliflora* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

5.4.3 Effect of defoliation on shoot growth inside and outside the floodplain

The shoot height measurements were subjected to three-way ANOVA, the three factors being defoliation regime (treatment), subsample and location. The shoots of the surviving seedlings of all the subsamples were longer inside compared to outside the floodplain in all the treatments. The three factors, treatment ($F_{[3,\ 62]} = 62.02$, $P < 0.001$) subsample ($F_{[3,\ 62]} = 163.39$, $P < 0.001$) and location ($F_{[1,\ 62]} = 119.21$, $P < 0.001$) had very significant effects on shoot lengths. There was also a significant interaction effect between treatment and location

(F $_{[3, 62]}$ = 3.45, P < 0.05) and a very significant effect between subsample and location (F $_{[3, 62]}$ = 13.56, P < 0.001) on shoot length. However, the interaction between treatment and subsample and that between the three factors did not affect shoot length (P > 0.05). The mean shoot length and standard errors of subsamples per treatment inside and outside the floodplain are shown in figure 5.3.

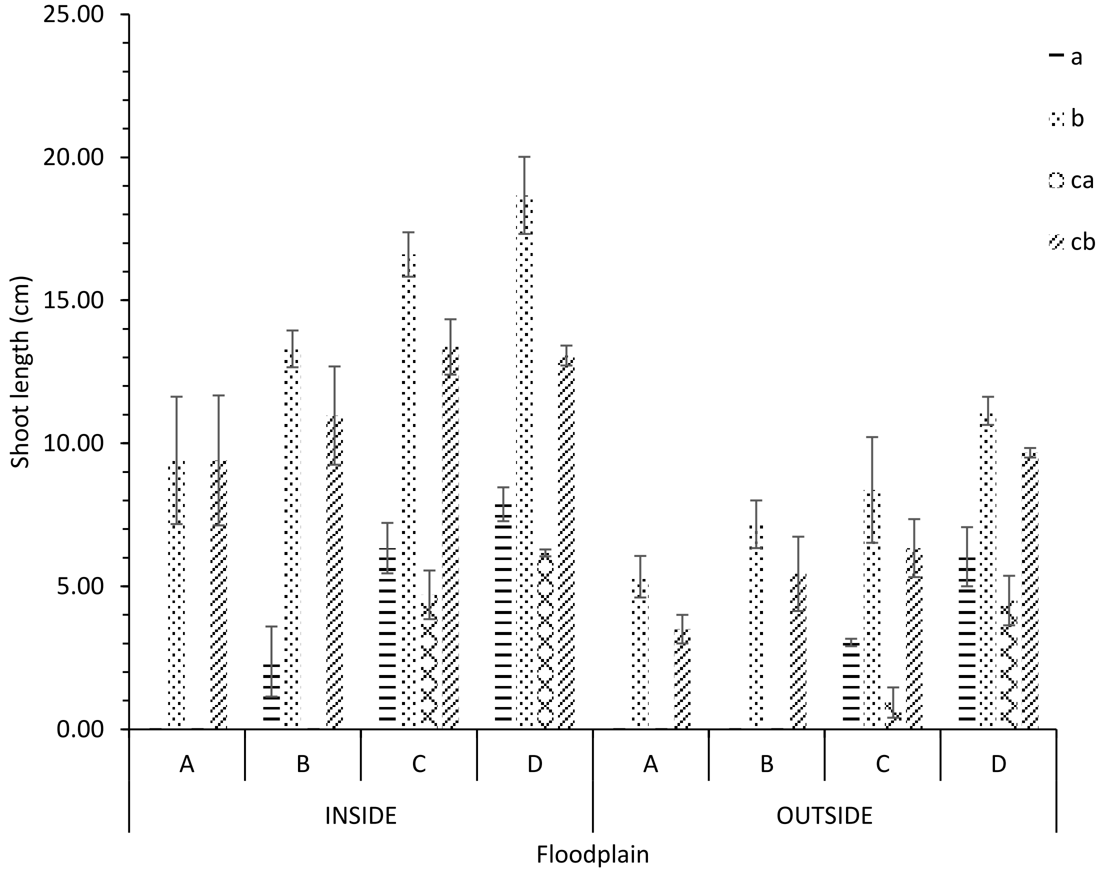

Figure 5.3: Mean shoot height (cm) and standard errors of subsample seedlings per treatment inside and outside the floodplain

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant interaction effect between treatment and location implied that the effect of a particular treatment on shoot height was dependent on the location. The results of Fisher's protected LSD test to identify the location and treatment interactions that were significant is shown in table 5.6. Seedling shoot height was significantly higher inside the floodplain compared to outside the floodplain in all the defoliation treatments. Inside the floodplain, shoot height increased as defoliation was intensified, being highest in treatment D (cultivated plots), but there was no significant difference in shoot length in heavily defoliated and cultivated plots. The shoot height also increased as defoliation was intensified outside the floodplain, but the difference in shoot height in moderately defoliated and not defoliated plots was not significant. Thus, the conditions inside the floodplain enhanced shoot growth more than those outside the floodplain, whereas herbaceous vegetation inhibited growth.

Table 5.6: Fisher's protected LSD test results for mean shoot height of seedlings in the treatment and location interactions. The means with different superscripts are significantly different.

Treatment.location	Mean
D.Inside floodplain	11.4^a
D.Outside floodplain	7.8^b
C.Inside floodplain	10.3^a
C.Outside floodplain	4.7^c
B.Inside floodplain	6.7^b
B.Outside floodplain	3.2^d
A.Inside floodplain	4.7^c
A.Outside floodplain	2.2^d

Key:
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

There was also a significant interaction effect between subsample and location, meaning that the impact of location on shoot height depended on the subsample. The results of Fisher's protected LSD test to identify the subsample and location interactions that were significant are shown in table 5.7.

Table 5.7: Fisher's protected LSD test results for mean shoot height of seedlings in the location and subsample interactions. The means with different superscripts are significantly different.

Location.subsample	Mean
Inside floodplain.b	14.5^{a}
Outside floodplain.b	8.0^{c}
Inside floodplain.cb	11.7^{b}
Outside floodplain.cb	6.6^{d}
Inside floodplain.a	4.1^{e}
Outside floodplain.a	2.3^{f}
Inside floodplain.ca	2.7^{f}
Outside floodplain.ca	1.4^{f}

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1

The shoot heights of all the surviving subsamples were significantly higher inside the floodplain compared to outside the floodplain. Planting *Acacia tortilis* and *Prosopis juliflora* together in the same plots reduced shoot height of the two species both inside and outside the floodplain. The reduction in shoot height was significant for *Prosopis juliflora* both inside and outside the floodplain. In the case of *Acacia tortilis,* the reduction in shoot height was significant inside the floodplain, but not outside the floodplain. The shoot of *Prosopis juliflora* was significantly longer than that of *Acacia tortilis*, whether planted in separate plots (subsample b) or together with *Acacia tortilis* in the same plots (subsample cb), both inside and outside the floodplain.

5.4.4 Effect of defoliation on taproot growth inside and outside the floodplain

The taproot data were subjected to three-way ANOVA; the three factors were defoliation regime (treatment), subsample and location. All the factors under consideration, treatment ($F_{[3, 62]} = 68.66$, $P < 0.001$) subsample ($F_{[3, 62]} = 126.08$, $P < 0.001$) and Location ($F_{[1, 62]} = 85.61$, $P < 0.001$) had very significant effects on taproot length. There was also a significant interaction effect between treatment and location ($F_{[3, 62]} = 8.87$, $P < 0.05$) and between treatment and subsample ($F_{[9, 62]} = 4.45$, $P < 0.001$) on taproot length. However, the interaction between location and subsample and that between the three factors did not have a significant effect on taproot length ($P > 0.05$). The mean taproot length and standard errors of subsamples per treatment inside and outside the floodplain are shown in figure 5.4.

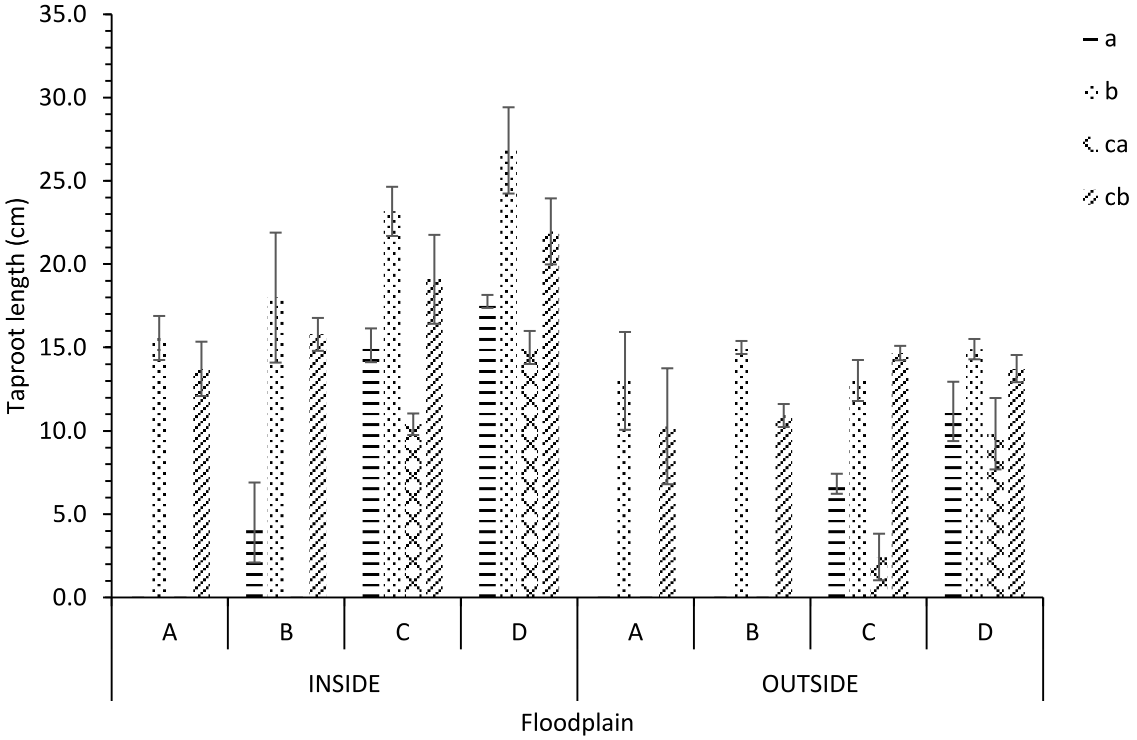

Figure 5.4: Mean taproot length (cm) and standard errors of subsample seedlings per treatment inside and outside the floodplain

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant interaction effect between treatment and location implied that the effect of a particular defoliation treatment on taproot length depended on the location, whether inside or outside the floodplain. The results of Fisher's protected LSD test to identify the location and treatment interactions that were significant are shown in table 5.8. Seedling taproot was significantly longer inside the floodplain compared to outside the floodplain in all treatments except in treatment A where the difference was insignificant. Inside the floodplain, taproot length increased significantly between treatments as defoliation was intensified, being longest in treatment D (total removal of herbaceous vegetation). The same was true outside the floodplain, but there was an insignificant difference in taproot length between treatments A and B. Thus, the conditions inside the floodplain enhanced growth of the taproot (like that of the shoot) compared to those outside the floodplain, whereas herbaceous vegetation inhibited taproot growth.

Table 5.8: Fisher's protected LSD test results for mean taproot length of seedlings in the treatment and location interactions. The means with different superscripts are significantly different.

Treatment.location	Mean
D.Inside floodplain	20.4^{a}
D.Outside floodplain	12.4^{c}
C.Inside floodplain	17.0^{b}
C.Outside floodplain	9.2^{de}
B.Inside floodplain	9.6^{d}
B.Outside floodplain	6.5^{f}
A.Inside floodplain	7.3^{ef}
A.Outside floodplain	5.8^{f}

Key:
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant subsample and treatment interaction effect implied that the impact of the defoliation treatment given on the taproot length depended on the subsample. The results of Fisher's protected LSD test to identify the subsample and treatment interactions that were significant are shown in table 5.9. The taproot of subsample b was shortest in treatment A and increased as defoliation was intensified, being longest in treatment D where there was no herbaceous vegetation. However, there was no significant difference in the taproot length of subsample b between any of the treatments. Subsample a did not survive under treatment A in any plot, but the taproot of this subsample increased significantly in length between treatments from treatment B to treatment D. For subsample cb, taproot length increased as defoliation was intensified, but there were no significant differences between treatments A and B and between treatments C and D. There were no surviving seedlings of subsample ca in any plot in moderately defoliated and not defoliated plots. However, the taproot length of subsample ca differed significantly between treatments C and D. Planting *Prosopis juliflora* and *Acacia tortilis* together in the same plot (subsamples cb and ca) reduced the taproot length of both species compared to when they were planted in separate plots (subsamples b and a). However, the difference in taproot length between subsamples b and cb was significant only in treatment B, and that between subsamples a and ca in treatment C only. In all the treatments, the tap root of *Prosopis juliflora* was significantly longer than that of *Acacia tortilis*, whether they were growing in separate plots (subsamples b and a) or together in the same plot (subsamples cb and ca).

Table 5.9: Fisher's protected LSD test results for mean taproot length of seedlings in the subsample and treatment interactions. The means with different superscripts are significantly different.

Subsample.treatment	Mean
P. juliflora. D	20.9^{a}
P. juliflora. C	18.1^{ab}
P. juliflora. B	16.5^{bc}
P. juliflora.A	14.3^{cd}
A. tortilis. D	14.5^{cd}
A. tortilis. C	11.0^{e}
A. tortilis. B	2.3^{g}
P. juliflora (a). D	17.9^{ab}
P. juliflora (a). C	16.9^{bc}
P. juliflora (a). B	13.4^{de}
P. juliflora (a). A	12.0^{de}
A. tortilis (b). D	12.4^{de}
A. tortilis (b). C	6.4^{f}

Key:
(a) = mixed with *A. tortilis* in the ratio 1:1
(b) = mixed with *P. juliflora* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

5.4.5 Effect of defoliation on biomass inside and outside the floodplain

The biomass data were subjected to three-way ANOVA, the three factors being defoliation treatment, subsample and location. All the factors under consideration, treatment ($F_{[3, 62]} = 54.93$, $P < 0.001$) subsample ($F_{[3, 62]} = 114.85$, $P < 0.001$) and location ($F_{[1, 62]} = 101.42$, $P < 0.001$) had very significant effects on seedling biomass. There were very significant interaction effects between subsample and location ($F_{[3, 62]} = 20.72$, $P < 0.001$), between treatment and location ($F_{[3, 62]} = 7.02$, $P < 0.001$) and between treatment and subsample ($F_{[9, 62]} = 3.41$, $P < 0.05$) on seedling biomass. However, the interaction effect among the three factors on seedling biomass was not significant ($P > 0.05$). The mean biomass and standard errors of subsamples per treatment inside and outside the floodplain are shown in figure 5.5.

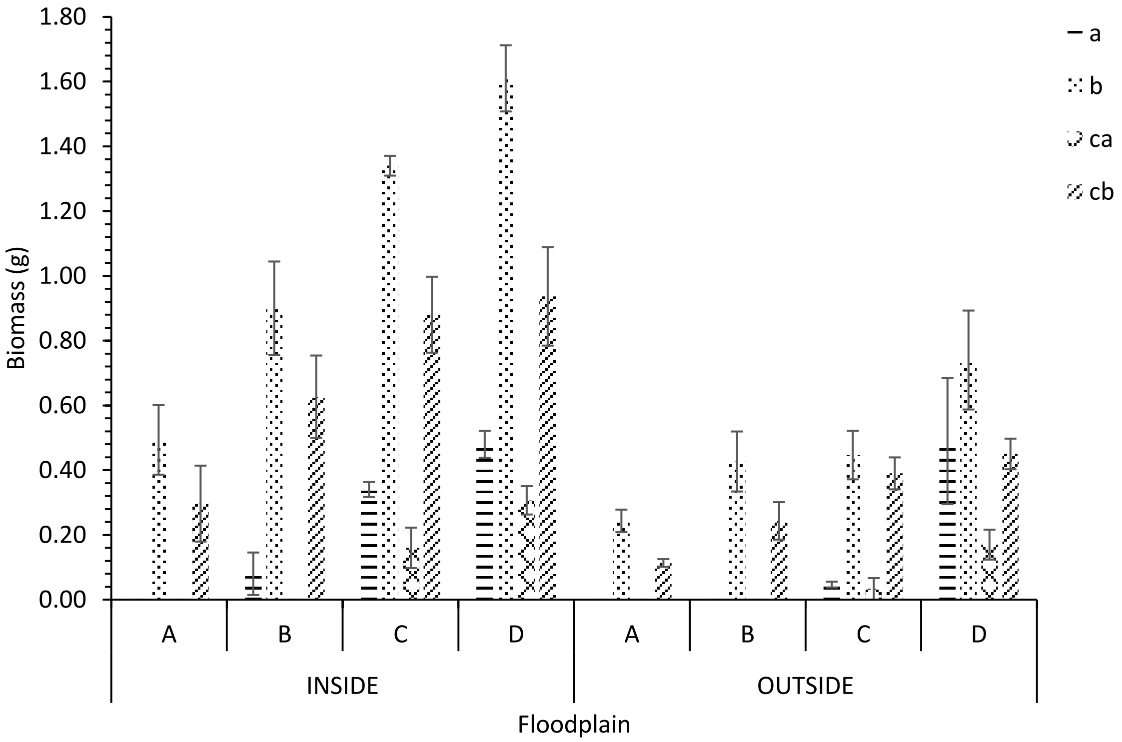

Figure 5.5: Mean biomass (g) and standard errors of subsample seedlings per treatment inside and outside the floodplain

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant interaction effect between subsample and location implied that the impact of location on the biomass of seedlings depended on the subsample. The results of Fisher's protected LSD test to identify the location and subsample interactions that were significant are shown in table 5.10. The biomass of subsample b and that of subsample cb was significant inside the floodplain than outside. The biomass of subsample a and that of subsample ca were higher inside the floodplain compared to outside, but the difference was not significant. Planting *Prosopis juliflora* and *Acacia tortilis* together in the same plot (subsamples cb and ca) reduced the biomass of the former species significantly compared to when planted in separate plots (subsample b). However, the biomass of *Acacia tortilis* was not reduced significantly by planting the two species in the same plot. These findings applied both inside and outside the floodplain for both species. In both locations, the biomass of *Prosopis juliflora* was significantly higher than that of *Acacia tortilis*, whether planted together in the same plot or in separate plots.

Table 5.10: Fisher's protected LSD test results for mean biomass of seedlings in the location and subsample interactions. The means with different superscripts are significantly different.

Location.subsample	Mean
Inside floodplain.b	1.09^{a}
Outside floodplain.b	0.46^{c}
Inside floodplain.cb	0.67^{b}
Outside floodplain.cb	0.27^{d}
Inside floodplain.a	0.23^{de}
Outside floodplain.a	0.13^{ef}
Inside floodplain.ca	0.12^{ef}
Outside floodplain.ca	0.05^{f}

Key:
a = *A. tortilis*
b = *P. juliflora*
ca = *A.tortilis* mixed with *P. juliflora* in the ratio 1:1
cb = *P. juliflora* mixed with *A. tortilis* in the ratio 1:1

The significant interaction effect between treatment and location implied that the effect of a particular defoliation treatment on seedling biomass depended on the location. The results of Fisher's protected LSD test to identify the treatment and location interactions that were significant are shown in table 5.11. Seedling biomass was significantly higher inside the floodplain compared to outside the floodplain in all treatments except in treatment A where the difference was insignificant. Inside the floodplain, biomass increased significantly from one treatment to the other as defoliation was intensified, being highest in treatment D (total removal of herbaceous vegetation). Outside the floodplain, there was no significant difference in biomass between treatments A, B, and C, but the difference was significant between treatment D and all the other treatments. Thus, the conditions inside the floodplain significantly enhanced seedling biomass compared to those outside the floodplain, whereas herbaceous vegetation reduced seedling biomass.

Table 5.11: Fisher's protected LSD test results for mean biomass of seedlings in the treatment and location interactions. The means with different superscripts are significantly different.

Treatment.location	Mean
D.Inside floodplain	0.83^{a}
D.Outside floodplain	0.46^{c}
C.Inside floodplain	0.66^{b}
C.Outside floodplain	0.20^{d}
B.Inside floodplain	0.40^{c}
B.Outside floodplain	0.17^{d}
A.Inside floodplain	0.20^{d}
A.Outside floodplain	0.09^{d}

Key:
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

The significant subsample and treatment interaction effect implied that the impact of the defoliation treatment given on the biomass depended on the particular subsample. The results of Fisher's protected LSD test to identify the subsample and treatment interactions that were significant are shown in table 5.12. The biomass of subsample b was least in treatment A and increased significantly between treatments as defoliation was intensified, being highest in treatment D where there was no herbaceous vegetation. Subsample a did not survive under treatment A, but its biomass increased significantly between treatments B, C and D. For subsample cb, biomass increased as defoliation was intensified from treatment A to treatment D, with a significant difference between treatments A and B. There were no surviving seedlings of subsample ca in any plot under treatments A and B by the end of the experimental period. However, biomass was higher in treatment D compared to that in treatment C although the difference was not significant. Planting *Prosopis juliflora* and *Acacia tortilis* together in the same plot (subsamples cb and ca) significantly reduced the biomass of *Prosopis juliflora* in all the treatments compared to when it was planted in separate plots (subsample b). Planting *Prosopis juliflora* together with *Acacia tortilis* in the same plot reduced the biomass of the latter species in treatments C and D, but the reduction was only significant in treatment D. In all the treatments where seedlings of *Prosopis juliflora* and *Acacia tortilis* were growing in separate plots (subsamples b and a), the biomass of *Prosopis juliflora* was significantly higher than that of *Acacia tortilis*. Comparison between treatments in separate plots and where the two species were in the same plot showed that the biomass of *Acacia tortilis* was reduced in treatments C and D, but the reduction was significant only in treatment D. Hence, planting the two species in close proximity and herbaceous vegetation reduced the biomass of *Acacia tortilis*.

Table 5.12: Fisher’s protected LSD test results for mean biomass of seedlings in the subsample and treatment interactions. The means with different superscripts are significantly different.

Subsample.treatment	Mean
P. juliflora. D	1.18^{a}
P. juliflora. C	0.89^{b}
P. juliflora. B	0.66^{c}
P. juliflora.A	0.37^{ef}
A. tortilis. D	0.49^{de}
A. tortilis. C	0.19^{gh}
A. tortilis. B	0.04^{hi}
P. juliflora (a). D	0.69^{c}
P. juliflora (a). C	0.55^{cd}
P. juliflora (a). B	0.44^{de}
P. juliflora (a). A	0.21^{fg}
A. tortilis (b). D	0.24^{fg}
A. tortilis (b). C	0.10^{gh}

Key:
(a) = mixed with *A. tortilis* in the ratio 1:1
(b) = mixed with *P. juliflora* in the ratio 1:1
A = Not defoliated
B = Moderately defoliated
C = Heavily defoliated
D = Bare soil

5.5 Discussion

Ecologists are becoming increasingly concerned about the negative effects caused by invasive alien species globally and locally. These species affect biodiversity ecologically, socially and economically (Mwangi & Swallow, 2005). One such invasive plant is *Prosopis juliflora* which has been introduced and naturalized in the last one and a half centuries in the continents of Australia, Asia and Africa (Pasiecznik *et al.* 2001). Previous studies have documented the importance of invasive plant species in being able to displace indigenous plants (Tilman, 1997; Davis *et al.* 2000; Kolb *et al.* 2002). Studies by Muturi *et al.* (2009) and Getachew *et al.* 2012 have shown the ability of *Prosopis juliflora* to gradually displace *Acacia tortilis* in Kenya and in India respectively. These studies are based on field surveys comparing the occurrence of the two adult species at a given time compared to their occurrence in previous studies. The current study was a field experimental set up to compare the two species in their early stages of development in terms of emergence, survival and growth as affected by different levels of defoliation inside and outside the floodplain. The different levels of defoliation simulated different grazing intensities whereas the dug plots with no herbaceous vegetation simulated cultivated land.

5.5.1 Effect of floodplain on emergence, survival and growth of seedlings

As reported in sections 5.4.1 and 5.4.2, the number of *Acacia tortilis* and *Prosopis juliflora* seedlings that emerged and survived inside the floodplain were significantly more than those that emerged and survived outside the floodplain. This was irrespective of whether the seeds were planted in separate plots (subsamples a and b) or together in the same plot (subsamples ca and cb). Similarly, the growth of seedlings of both *Prosopis juliflora* and *Acacia tortilis* as indicated by the biomass, shoot height and taproot length was significantly more inside the floodplain than outside the floodplain (sections 5.4.3, 5.4.4 and 5.4.5). Inside or outside the floodplain, significantly more seedlings of *Prosopis juliflora* emerged and survived compared to those of *Acacia tortilis.* Its growth was also significantly more than that of *Acacia tortilis.* Thus, post-germination mortality was very high and the growth much less for *Acacia tortilis* compared to *Prosopis juliflora*. These findings were true whether the seeds of the two species were planted in separate plots or together in the same plot.

A study by Mworia *et al*. (2011) in upper Tana River found that establishment of *Prosopis juliflora* was higher inside the floodplain than outside and attributed this to availability of more resources in the former. In another study carried out by Rohner and Ward (1999) in the Middle East, water availability was found to be one of the main determinants of *Acacia tortilis* seedling survival. Another study in Turkwel riverine forest in Kenya showed that extended rainfall favoured the recruitment of *Acacia tortilis* seedlings (Stave *et al.* 2006). The studies above emphasize the value of water in seedling recruitment and survival, and perhaps explain why emergence, survival and growth were significantly higher inside the floodplain than outside for both species. Floods provided water and nutrients that enhanced taproot length, shoot height and biomass accumulation of seedlings, which were significant in the floodplain. Indeed, the findings in chapter 4 indicated that the floodplain had significantly more nutrients and water compared to the areas outside the floodplain. However, *Prosopis juliflora* outcompeted *Acacia tortilis*, confirming the competitive nature of invasive plants compared to indigenous plants (Tilman, 1997; Davis *et al.* 2000; Kolb *et al.* 2002).

Planting *Prosopis juliflora* and *Acacia tortilis* seeds together in the same plot illustrated possible competition for resources between the two species when growing in close proximity. Generally, more seedlings of *Acacia tortilis* and *Prosopis juliflora* emerged and survived in plots where they were planted separately compared to where they were planted together in the same plot, both inside and outside the floodplain. This implied that emergence and survival of both *Acacia tortilis* and *Prosopis juliflora* were reduced by planting them together in the same plot. Post-germination mortality of seedlings was probably higher when the seedlings of *A. tortilis* and *P. juliflora* grew in close proximity within the same plot compared to when they grew in different plots. Some seeds of *Acacia tortilis* started to germinate but failed to emerge above the soil surface while others emerged but the seedlings failed to survive due to insufficient moisture as are consequence of erratic rainfall. Rohner & Ward (1999) found the main limiting factor for long-term survival of *Acacia tortilis* to be its high post-germination seedling mortality. Planting seeds of both species in the same plot also inhibited the seedling growth of both species, although the seedlings of *Prosopis juliflora* grew significantly faster than those of *Acacia tortilis. Prosopis juliflora* was thus more competitive for resources compared to *Acacia tortilis.* This resulted to reduced emergence, survival and growth of the latter, both inside and outside the floodplain. The implication of the results is that *Prosopis julifora* can reduce the density of *Acacia tortilis* and by extension the density of other indigenous plant species. *Prosopis* does this by limiting their emergence, survival and growth, eventually displacing them and reducing species diversity in the community.

5.5.2 Effect of defoliation and cultivation on emergence, survival and growth of seedlings

A number of researchers have shown that livestock grazing in dryland rangelands reduces the herbaceous vegetation layer and increases the density of woody plants (Archer & Smeins, 1991; Scholes & Archer 1997; Polley *et al*. 2002; Chirara & Dijkman, 2002). In the current study, the more intense the defoliation the higher the number of *Acacia tortilis* and *Prosopis juliflora* seedlings that emerged and survived, with significantly more seedlings emerging and surviving where herbaceous vegetation was totally removed and the plots dug to simulate cultivation. Similarly, the growth of the two species as indicated by their biomass, shoot height and taproot length increased as defoliation intensified and was significantly more where herbaceous vegetation was totally removed and the plots dug. Livestock overgrazing reduces herbaceous cover, relaxes grass competition and hence facilitates woody seedling establishment (Archer & Smeins, 1991; Scholes & Archer, 1997). The results of this study concur with the findings of the above researchers concerning woody species encroachment being facilitated by intense grazing. Moreover, the results also show that cultivation significantly enhanced woody species emergence, survival and growth, both inside and outside the floodplain. The findings also support those of another study in lower Turkwel River in Kenya by Oba *et al.* (2002) who found that regeneration of *Acacia tortilis* was greater where cultivation was active than in fallow farms.

Both indigenous and invasive plants are capable of encroaching rangelands as defoliation is intensified. However, in all the defoliation treatments, *Prosopis juliflora* performed better than *Acacia tortilis* in terms of emergence, survival and growth, both inside and outside the floodplain. The high emergence, survival and growth ability of *Prosopis juliflora* implied that it is more competitive for resources compared to *Acacia tortilis* and hence can encroach rangelands faster. It also suggests that *Acacia tortilis* can easily be displaced by *Prosopis juliflora* if the two species are growing in close proximity. A research by Andersen and Krzywinski (2007) in an Egyptian desert found the mortality and recruitment of *Acacia tortilis* to be high and low respectively. In this study, the mortality of *Acacia tortilis* was high and its recruitment low due to low moisture, which was further reduced by *Prosopis juliflora*.

Competition between woody seedlings and herbaceous vegetation for resources varied depending on location (inside or outside the floodplain) and on the level of defoliation. When planted in separate plots *Prosopis juliflora* survived in all treatments inside and outside the floodplain. *Acacia tortilis* did not survive inside and outside the floodplain where herbaceous vegetation was not defoliated, suggesting that herbaceous vegetation was more competitive for resources than *Acacia tortilis* seedlings, unlike *Prosopis juliflora*. The competition was enhanced by the conditions outside the floodplain, resulting to mortality of *Acacia tortilis* even when herbaceous vegetation was moderately defoliated. Survival of *Acacia tortilis,* unlike that of *Prosopis juliflora*, was even more threatened by planting seeds of the two species together in the same plot, resulting to increased mortality and less growth. Seedlings of *Acacia tortilis* did not emerge outside the floodplain in any plot where herbaceous vegetation was not defoliated whereas those of *Prosopis juliflora* emerged in all plots under all defoliation treatments. Moreover, the seedlings of *Acacia tortilis* which had emerged inside the floodplain where herbaceous vegetation was not defoliated and in moderately defoliated vegetation inside and outside the floodplain did not survive to the end of the three month period. Thus, *Prosopis juliflora* was more competitive for resources than *Acacia tortilis,* hence the mortality of the latter species in plots where herbaceous vegetation was not defoliated as well as in plots where the vegetation was moderately defoliated.

A field study by Chirara *et al.* (1999) in south-west Zimbabwe found that competition between *Acacia karroo* seedlings and grasses was higher in the dry season than the wet season, resulting to mortality of the seedlings. This concurs with the current study which shows that competition between woody seedlings and herbaceous vegetation was higher outside than inside the floodplain, resulting to higher mortality and less growth of the seedlings. However, the mortality of *Acacia tortilis* was significantly higher and its growth significantly less than the case for *Prosopis juliflora*. Brown *et al.* (1998) conducted a greenhouse experiment and found that defoliation of grass did not affect the emergence, survival and biomass of *Acacia nilotica*, which contradicts the findings of this research. In another greenhouse experiment by Chirara *et al.* (2002), the biomass of *Acacia karroo* seedlings that grew in heavily clipped grasses was higher than that of the seedlings that grew in moderately clipped grass. Chirara & Dijkman (2002) also found unclipped grass to significantly reduce *Acacia karroo* biomass production under both dry and wet conditions. These findings concur with those of the current research despite the difference in the species involved.

5.5.3 Relevance of results to management of *P. juliflora* and promotion of *A. tortilis*

The results of this study show that cultivated plots were more susceptible to invasion as shown by the emergence, survival and growth of *Prosopis juliflora* which were significantly higher than those of *Acacia tortilis*. In Tana River County, the fallow system of farming is practiced inside the floodplain mainly by the Pokomo, the dominant tribe in the region. In this system, a family leaves a portion or the whole plot fallow for a period of time to regain fertility. This traditional culture, though essentially good, is likely to encourage proliferation of *Prosopis juliflora* which has already been introduced in the region. The current study shows that regeneration of both *Acacia tortilis* and *Prosopis juliflora* was significantly high in cultivated plots. *Oba et al.* 2002 also found regeneration of *Acacia tortilis* to be greater where cultivation was active than in fallow farms in lower Turkwel River in Kenya. Despite the possible threat of invasion as a result of cultivation, measures can be taken to contol the establishment of *Prosopis juliflora* seedlings. Frequent weeding would ensure that seedlings of *Prosopis juliflora* are uprooted early before they become established and difficult to uproot, while those of selected indigenous plants like *Acacia tortilis* are retained. Farms should be left fallow for a shorter period of time if need be, and frequent weeding would ensure that by the time the farms are left fallow the density of *Prosopis juliflora* is minimal. Sensitization of the communities that practice shifting cultivation is necessary for them to take the responsibility of controlling the spread of *Prosopis juliflora* by consistently uprooting the seedlings. Other methods of increasing fertility can be used such as using farmyard manure, compost manure and planting leguminous crops. In addition, crop rotation can be practiced to reduce soil erosion and help retain soil fertility.

The results of this study have also shown that heavy herbaceous defoliation increases proliferation of *Prosopis juliflora* through enhanced emergence, survival and growth. Moreover, the proliferation of this invasive plant was significantly higher inside than outside the floodpain, implying that the conditions inside the floodplain were more favourable. In Tana River County, the floodplain is used as a dry season refuge for livestock by the surrounding pastoralists, mainly the Somali, Orma and Wardei, inevitably increasing grazing intensity. Thus, the conditions inside the floodplain and increased grazing pressure would have a synergistic effect on the proliferation of *Prosopis juliflora*. To counter this, grazing pressure can be decreased by encouraging the pastoral communities to reduce their livestock and opt for other income generating ventures. Boreholes can also be sunk outside the floodplain for these communities to water their livestock and grow fodder crops.

In Tana River County, seasonal flooding in April and December occurs which represents an influx of nutrients and water inside the floodplain. The results show that emergence, survival and growth of both *Acacia tortilis* and *Prosopis juliflora* were significantly higher inside compared to outside the floodplain. However, the emergence, survival and growth of *Prosopis juliflora* was significantly higher than that of *Acacia tortilis*. An influx of resources inside the floodplain due to seasonal floods would further enhance emergence, survival and growth of *Prosopis juliflora*. The favourable conditions in the floodplain, cultivation and intense grazing favour the competitive ability of *Prosopis juliflora* over *Acacia tortilis* as shown by the results of this study. To counter this, digging and uprooting all the *Prosopis* *juliflora* and selectively retaining seedlings of *Acacia tortilis* prior to seasonal flooding would give the latter seedlings a headstart. The seedlings of the other indigenous woody plants should also be retained. Weeding consistently to get rid of any *Prosopis juliflora* seedlings that emerge would be helpful since it is easier to uproot the seedlings in the early stages of growth than later. Although it may not be possible to avert climate change or fully eradicate *Prosopis juliflora*, other threats like grazing of livestock inside the floodplain can be minimized. Designating specific areas within the floodplain for shallow wells, sub-surface dams and earth pans would also be helpful.

5.5.4 Relevance of results to modeling/predicating impacts of climate change

The trends in the *Prosopis juliflora - Acacia tortilis* balance in river floodplain systems can be predicted by superimposing the effects of climate change with those of grazing and cultivation in this study. According to Daehler *et al.* 2004, species invasion risk assessment models can generally be grouped into pre-introduction and post-introduction. The former predict the potential behaviour of a species prior to introduction and the latter focus on predicting the potential for range expansion after a species has become naturalized or invasive in the new area. Post- introduction, prediction of the potential for range expansion, is applicable in this case since *Prosopis juliflora* has already become naturalized in Tana River County. Ecological niche modeling is a commonly used approach to predict the potential of a species to expand in range in the face of changing environmental conditions. Such models firstly relate the present day species occurrence or geographical distribution data to ecological-environmental characteristics of the invaded habitat and then use the relationship to predict future changes in distributional areas. This means building on the known geographic occurrences to produce a species ecological niche model, which is projected in a changed climatic or environmental scenario to provide prediction of potential distribution. The field of individual species ecological niche modeling has blossomed over the last 3 decades largely as a response to the necessity to predict impacts of climate change. Moreover, replacement of natives by invasive species is predicted to be one of the major impacts of climate change (Low, 2008).

Many ecological niche models lay more emphasizes on physiological attributes as compared to environmental or geographic conditions. The basis of this is that ecophysiological trait differences between the invader and indigenous species can greatly influence resource efficiency and production. This is the case between invasive *Prosopis juliflora* and native *Acacia tortilis* in this study. The important ecophysiological trait differences identified in this study which can be applied in modeling invasion in Tana River County and similar River floodplains include emergence, survival and growth of seedlings. *Prosopis juliflora* out performed *Acacia tortilis* in similar conditions as summarized below:

- Fewer seedlings of both species emerged and survived outside compared to inside the floodplain, but those of *Acacia tortilis* were significantly fewer than those of *Prosopis juliflora* in both cases.
- Fewer seedlings of *Acacia tortilis* emerged and survived compared to those of *Prosopis juliflora*, whether planted in separate plots or together in the same plot
- The growth of both species as depicted by the shoot height, taproot length and biomass was less outside compared to inside the floodplain, but the growth of *Acacia tortilis* was less than that of *Prosopis juliflora*
- The mean shoot height, taproot length and biomass accumulation of *Prosopis juliflora* were higher than those of *Acacia tortilis*, whether planted in separate plots or together in the same plot.

- Increased herbaceous vegetation defoliation enhanced emergence, survival and growth of seedlings of both species, but more so for *Prosopis juliflora* than for *Acacia tortilis.*
- Cultivation enhanced emergence, survival and growth of seedlings of both species, but more so for *Prosopis juliflora* than for *Acacia tortilis.*

Empirical evidence suggests that it is climate variability – extreme climate years (e.g. droughts and El Nino events) that influence species dynamics more than change in yearly mean climate (Lovejoy & Hannah, 2006). In addition, the frequency of these events is predicted to increase in East African savannas (Adger *et al.* 2003). Based on the ecophysiological trait differences between *Prosopis juliflora* and *Acacia tortilis*, predictions can be made about their balance in river floodplain systems. Based on the results of this study, the impact of droughts and floods in Tana River floodplains on the *Prosopis juliflora* - *Acacia tortilis* balance is predicted to be as follows:

- Floods will increase invasion, especially inside the floodplain because more propagules and nutrients will be transported into the floodplain which already has more resources and more land under cultivation.
- Prolonged droughts will also increase invasion inside the floodplain where grazing of livestock is intensified and the longer taproots of *Prosopis juliflora* can readily access ground water. In addition, *Acacia tortilis* pods are consumed or harvested for livestock feed during drought periods.
- The synergistic effects of environmental (climate variability), anthropogenic (cultivation and livestock grazing), plant ecophysiology (plant physiology and soil condition) will likely increase *Prosopis juliflora* invasion.

Intergovernmental Panel on Climate Change (IPCC, 2007) predicted that extreme events, such as floods and droughts, would occur more often and with greater severity. Thus, *Prosopis juliflora* invasion is predicted to increase, further reducing the density of *Acacia tortilis* and by extension that of the other indigenous plants. This will in turn affect the diversity, abundance and nutritional quality of foliage available to livestock.

5.6 Conclusion

This study compared the emergence, survival and growth of *Acacia tortilis* and *Prosopis juliflora* under different defoliation regimes inside and outside the floodplain in Tana River County. The defoliation regimes simulated different grazing intensities and included total removal of herbaceous vegetation and digging which simulated cultivation. The results have shown that the floodplain, grazing intensity and cultivation all affected emergence, survival and growth of both *Acacia tortilis* and *Prosopis juliflora.*

The emergence, survival and growth of both species were significantly higher inside than outside the floodplain. Significantly more seedlings of *Prosopis juliflora* emerged and survived compared to those of *Acacia tortilis*. The growth of *Prosopis juliflora* was also significantly more than that of *Acacia tortilis*. These findings were true whether the seeds of these woody species were planted in separate plots or together in the same plot. However, planting the seeds together in the same plot reduced emergence, survival and growth of these woody plant seedlings compared to when seeds were planted in separate plots. This suggests that competition between *Acacia tortilis and Prosopis juliflora* was more intense when the seeds were planted in the same plot compared to when seeds of each species were planted in separate plots.

Herbaceous vegetation reduced the emergence, survival and growth of both *Acacia tortilis* and *Prosopis juliflora* both inside and outside the floodplain. The emergence, survival and growth were higher for *Prosopis juliflora* than for *Acacia tortilis* in both cases under all the defoliation treatments. The higher the defoliation intensity the more seedlings emerged and survived, and the faster the growth of the woody plant seedlings. Emergence, survival and growth of woody plant seedlings were significantly higher in cultivated plots, but significantly higher for *Prosopis juliflora* than for *Acacia tortilis*. Consequently, invasion would occur faster on cultivated land compared to land that is uncultivated.

CHAPTER SIX: EFFECTS OF SITE CHARACTERISTICS AND SOIL TREATMENTS ON GROWTH PERFORMANCE OF *A. tortilis* AND *P. juliflora*

6.1 Introduction

Plant survival and growth are affected by many factors which may vary for indigenous and invasive plant species. These factors include plant-soil feedbacks (Pasiecznik *et al.* 2001; Ehrenfeld *et al.* 2005; Kulmatiski *et al*. 2008; Bever *et al.* 2010; Getachew *et al.* 2012; Andersen *et al*. 2015). Plant-soil feedbacks are processes where plants change the biotic and abiotic qualities of the soil in which they grow, altering the ability of plants to grow in that soil in the future. The feedbacks can be positive or negative and include alteration of the structure, chemistry, and microbial community of soil via root exudates and leaf litter (Ehrenfeld *et al*. 2005; Bever *et al.,* 2010; Getachew *et al.* 2012; Andersen *et al*. 2015)). In addition, Light, temperature and soil moisture also influence plant germination, survival and growth (Ehrenfeld *et al.* 2005), as can the taproot length of a plant (Felker *et al.* 1983). Prolonged rainfall, drought, browsing and trampling also affect plant regeneration (Stave *et al.* (2006) and therefore the persistence and abundance of plants. Other factors that affect plant survival and growth are shifting agriculture (Oba *et al*. 2002), soil fertility gradient (Belsky, 1992; Belsky *et al.* 1993), tree canopy cover (Smith & Shackleton 1988; Loth *et al*. 2005; Kahi *et al.* 2009) and competition between plants (Getachew *et al.* 2012).

Variation in the competitive ability of plant species may determine their persistence and abundance (Peltzer & Kochy, 2001) in different habitats and/or soil conditions. Some of the habitats which influence the performance of plants and have been studied include under tree canopies, in perennial grass and on bare soil (Smith & Shackleton 1988; Gomez-Aparicio *et al.* 2005; Loth *et al.* 2005; Kahi *et al.* 2009; Getachew *et al.* 2012; Caldeira *et al.* 2014). Tree canopy cover effects on germination, survival and growth may vary depending on the location of the study (e.g. Smith & Shackleton 1988 vs Loth *et al.* 2005), canopy position (Winkler *et al.* 2005) and the particular tree species (Kahi *et al.* 2009). Some researchers e.g. Caldeira *et al.* (2014) found that tree canopy cover facilitate seedling germination, survival and growth. Other researchers such as Loth *et al.* (2005) found that tree canopies inhibit seedling germination and growth. On the other hand, soils under *Acacia tortilis* have been found to facilitate herbaceous growth (Belsky, 1992; Belsky *et al.* 2003; Kahi *et al.* 2009) whereas those under *Prosopis juliflora* have been found to inhibit herbaceous growth (Kahi *et al.* 2009). Getachew *et al.* (2012) also showed that reponses to different habitats and soil conditions vary for different plants.

Acacia tortilis is one of the important indigenous plants whereas *Prosopis juliflora* is an important invader in Tana River County. *Acacia tortilis* has a number of values which include enhancing soil fertility (Belsky, 1992) and providing fodder for livestock (Reid & Ellis, 1995), especially during the drought periods. The tree provides firewood and charcoal for cooking and is an important medicinal plant that is used for treatment of asthma (Hagos *et al.* 1987). In addition, the pods of *Acacia tortilis* are quite nutritious and increase milk production of lactating animals (Le Houerou, 1980). Indeed, the pods and seeds are consumed by Turkana and Masai herd boys during drought periods in Kenya.

Prosopis juliflora on the other hand was introduced in Tana River County in the early 1980s together with other *Prosopis* species. These species have negative as well as positive benefits and are considered beneficial or otherwise depending on whether they meet the economic needs of people or not (Binggeli, 2001; Pasiecznic, 2001). For example, *Prosopis juliflora* is considered one of the most valuable tree species in the drylands of India (Pasiecznic, 2001).

In Baringo, Kenya, the plant is not considered beneficial (Mwangi & Swallow, 2005) because it has more disadvantages than advantages. This mindset was expected to change with the construction of Baringo Thermal Power Station which would use *Prosopis juliflora* stems supplied by the locals as raw materials, earning them an income. Unfortunately, the project has stalled and the residents' hope for income has faded (Daily Nation Newspaper, 2020). In Tana River County, *Prosopis juliflora* is not considered beneficial although permits have been issued allowing charcoal production using *Prosopis* plant. However, most of the charcoal beneficiaries are from outside the County and hence the local people do not appreciate the economic value of the plant.

According to Raghubanshi *et al.* (2005), invasive species successfully germinate under different conditions and outcompete native species. Hence, *Prosopis* species are expected to be more successful in different habitats and soil conditions compared to *Acacia* species. The success of *Prosopis* species is ascribed to production of a large number of seeds that are efficiently dispersed by wind, surface runoff and livestock (Shiferaw *et al*. 2004). Consumption of the pods by livestock also enhances seed viability and germination since they get scoured while passing through the animals' digestive tract (Felker, 2003; Andersen *et al.* 2015). In addition, the plant has a long taproot that enhances absorption of water and hence survival of seedlings during drought periods (Felker, 2003). The plant can therefore spread extremely rapidly, especially in its introduced range (Mwangi & Swallow, 2005).

The current study was conducted to determine the response of *Acacia tortilis* and *Prosopis juliflora* to similar site characteristics and soil conditions in terms of emergence, survival and biomass accumulation. Such a study, comparing *Acacia tortilis* and *Prosopis juliflora* in the early stages of their growth has not been done in Tana River County before. The study will indicate the competitive abilities of *Acacia tortilis* and *Prosopis juliflora* under similar environmental conditions. This is critical in the light of increasing invasion by *Prosopis juliflora*, grazing pressure and climate variability. The findings of this study will shed light on possible ways to promote regeneration of *Acacia tortilis* and control the spread of *Prosopis juliflora*. The unsustainable utilization of *Acacia tortilis* and the increasing invasion by *Prosopis juliflora* threatens the continued existence of the former species. This calls for sustainable utilization of *Acacia tortilis*, promotion of its regeneration and control of the invasive *Prosopis juliflora*.

6.2 Objectives

The main objective of the experiment was to determine the effects of site characteristics and different soil treatments on emergence, survival and biomass of *Acacia tortilis* and *Prosopis juliflora* seedlings. The specific objectives were two-fold:

- To determine the emergence, survival and biomass accumulation of *Acacia tortilis* and *Prosopis juliflora* planted under *Acacia tortilis* and *Prosopis juliflora* canopies, in perennial grass and on bare soil.
- To determine the emergence, survival and biomass of *Acacia tortilis and Prosopis juliflora* for seeds placed on the soil surface, those buried under cow dung and those buried under the soil in the habitats above.

6.3 Materials and methods

6.3.1 Study site

The field experiment was carried out within Hola primary school in Tana River County, Kenya. The school is located outside the floodplain between (01^{o}28′41.30″S, 040^{o}01′39.87″E) in Hola town. Tana River county has three sub-counties; Hola (also known as Galole), Bura and Garsen, the former being the administrative headquarters of the county.

The dominant ethnic groups in Hola are the Pokomo, most of whom are crop farmers, and the Orma and Wardei, who are predominantly livestock keepers. Other groups of people include the Waata and Boni who are culturally hunters and gatherers, the Wailwana /Malakote and the Bajuni. Besides these ethnic groups in Hola, the County is also home to other Kenyan ethnic groups, including the Somali, Luo, Kamba, Kikuyu and Kisii.

6.3.2 Experimental design

Listed below are four different types of habitats which were laid in duplicate within Hola primary school compound.

Habitat A: Under mature *Acacia tortilis* canopy

Habitat B: Under mature *Prosopis juliflora* canopy

Habitat C: In the perennial grass (*Tetrapogon bidentatus*)

Habitat D: On bare soil

Figures 6.1 and 6.2 below show mature *Prosopis juliflora* and *Acacia tortilis* trees respectively.

Figure 6. 1: A mature *Prosopis juliflora* (Sw.) DC. tree

Figure 6. 2: A mature *Acacia tortilis* (Forssk.) Hayne tree

In each habitat, three treatments were applied to the seeds of both plant species to simulate seeds on the soil surface, those in natural seed storage/soil seed bank and those excreted in cow dung:

a. Seeds placed on the soil surface
b. Seeds in 3cm thick layer of cow dung
c. Seeds under soil (1cm depth)

The cow dung was collected from zero grazed cows that were not exposed to *Prosopis juliflora* or *Acacia tortilis* seeds. Each habitat consisted of 18 PVC rings of 6cm high, diameter of 20cm, 9 rings in which *Prosopis juliflora* seeds were planted and 9 rings in which *Acacia tortilis* seeds were planted. The experiment was conducted for three months during the long rainy season in March. The seeds of *Prosopis juliflora* were obtained from the study area and those of *Acacia tortilis* from Kenya Agricultural Research Institute, Muguga. Germination of *Prosopis juliflora* seeds was initiated by scarification using 1N sulphuric acid for 40 minutes to simulate the digestive process of herbivores (Peláez *et al.* 1992). *Acacia tortilis* seeds were soaked in water and heated up to 90^o to break dormancy and left overnight to cool before sowing. Assignment of treatments to the rings was done randomly in 3x3 Latin square design for each seed type. Nine evenly spaced seeds of *Prosopis juliflora* or *Acacia tortilis* were planted in each ring. The number of seedlings of *Prosopis juliflora* and *Acacia tortilis* that emerged in the four habitats under the three soil treatments were counted weekly and recorded separately. The number of surviving seedlings was also noted and recorded fortnightly until the end of the rainy season. Thereafter, all the PVC rings were watered prior to uprooting the seedlings, enough to soften the soil and prevent damaging the seedlings. Two seedlings of *Prosopis Juliflora* or *Acacia tortilis* were randomly selected from PVC rings from each habitat type and from each soil treatment. The seedlings were placed separately inside weighed and labelled paper bags and an electronic weighing balance was used to weigh them. The drying of seedlings occurred naturally at room temperature. Weighing of seedlings was done weekly until the weight was constant, then the dry weight (biomass) was recorded in grams.

6.3.3 Data analysis

Comparison of means was done using Fisher's protected least significant difference (LSD), also at 5% significance level. The habitats were under *Acacia tortilis* canopy, under *Prosopis juliflora canopy,* in perennial grass and on bare soil in the open. The soil treatments were seeds placed on the soil surface, seeds under cow dung and seeds under the soil. The seeds that were covered with cow dung simulated seeds excreted in cow dung in areas used for livestock grazing. *Prosopis juliflora* and *Acacia tortilis* represented invasive and indigenous species respectively.

6.4 Results

6.4.1 Effects of habitats and soil treatments on emergence of seedlings

All the three factors under consideration, plant species ($F_{[1, 119]} = 136.73$, $P < 0.001$), habitat ($F_{[3, 119]} = 37.73$, $P < 0.001$) and treatment ($F_{[2, 119]} = 228.18$, $P < 0.001$) had very significant effects on the emergence of seedlings. The interactions between species and treatment ($F_{[2, 119]} = 22.96$, $P < 0.001$), species and habitat ($F_{[3, 119]} = 6.53$, $P < 0.001$) and between treatment and habitat ($F_{[6, 119]} = 3.41$, $P < 0.05$), also had significant effects on emergence of seedlings. None of the *Acacia tortilis* seeds that were placed on the soil surface emerged under *Prosopis juliflora* canopy and in perennial grass, but *Prosopis juliflora* seeds emerged in all the treatments and habitats (figure 6.3).

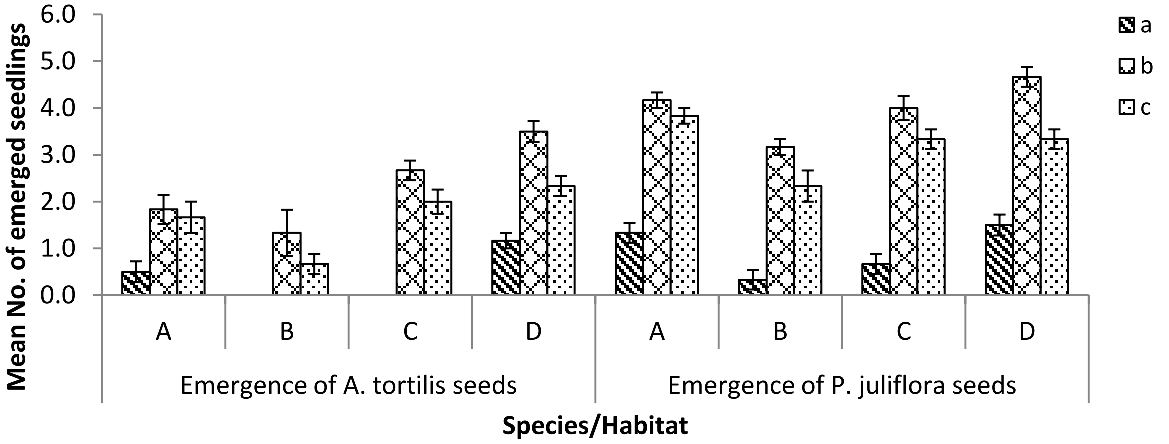

Figure 6.3: The mean number and standard errors of emerged *Acacia tortilis* and *Prosopis juliflora* seedlings per habitat for the different soil treatments

Key:

Defoliation treatments:	**Soil treatments:**
A = Not defoliated	a = Soil surface
B = Moderately defoliated	b = In cow dung
C = Heavily defoliated	c = Under soil
D = Total defoliation and dug soil	

The significant interaction effect between species and treatment implied that the impact of soil treatment on emergence varied depending on the species in question. Fisher's protected LSD test results (table 6.1) show that for both species, the number of seedlings that emerged was significantly less where the seeds were placed on the soil surface compared to the other treatments. However, the number of *Acacia tortilis* seedlings that emerged was not different compared to that of *Prosopis juliflora* in this treatment. The number of seedlings of both species that emerged was significantly more where seeds were in cow dung compared to where seeds were under the soil. However, the number of *Prosopis juliflora* seedlings that emerged was significantly more than those of *Acacia tortilis* in both soil treatments.

Table 6.1: Fisher's protected LSD test results for the mean number of emerged seedlings in the treatment and species interactions. The means with different superscripts are significantly different.

Treatment	**A. tortilis**	**P. juliflora**
Seeds on the soil surface	0.583^e	0.792^e
Seeds in cow dung	2.333^c	4.000^a
Seeds under the soil	1.667^d	3.208^b

The significant interaction effect between species and habitat implied that the effect of habitat on emergence of seedlings also varied depending on the species. Fisher's protected LSD test results (table 6.2) indicated that in all the habitats, the number of *Prosopis juliflora* seedlings that emerged were significantly more than those of *Acacia tortilis*. There was a significant difference in emergence of *Acacia tortilis* seedlings between all the habitats. However, in the case of *Prosopis juliflora* there was no significant difference in seedling emergence between the seeds planted under *Acacia tortilis* canopy and those planted on bare soil.

Table 6.2: Fisher's protected LSD test results for the mean number of emerged seedlings in the habitat and species interactions. The means with different superscripts are significantly different.

Habitat	**A. tortilis**	**P. juliflora**
Under *A. tortilis* canopy	1.333^d	3.111^a
Under *P. juliflora* canopy	0.667^e	1.944^c
In perennial grass	1.778^c	2.444^b
On bare soil	2.333^b	3.167^a

The significant interaction effect between treatment and habitat implied that the effect of the soil treatment given on seedling emergence of both species varied depending on the habitat. There was a significant difference in seedling emergence between all the soil treatments under *Acacia tortilis* and *Prosopis juliflora* canopies and on bare soil. In all the habitats, seedling emergence for the seeds placed on the soil surface was significantly less (figure 6.4). Seedling emergence was significantly more for the seeds in cow dung in all the habitats except in perennial grass. In this habitat, emergence of the seedlings in cow dung and those under the soil was not significantly different. For the seeds that were in cow dung and those under the soil, seedling emergence was significantly less where the seeds were planted under *Prosopis juliflora* canopy and significantly more on bare soil. For the seeds on the soil surface, seedling emergence was significantly less under *Prosopis juliflora* canopy and in perennial grass. However, there was no difference in seedling emergence for the seeds that were planted under *Acacia tortilis* canopy and on bare soil.

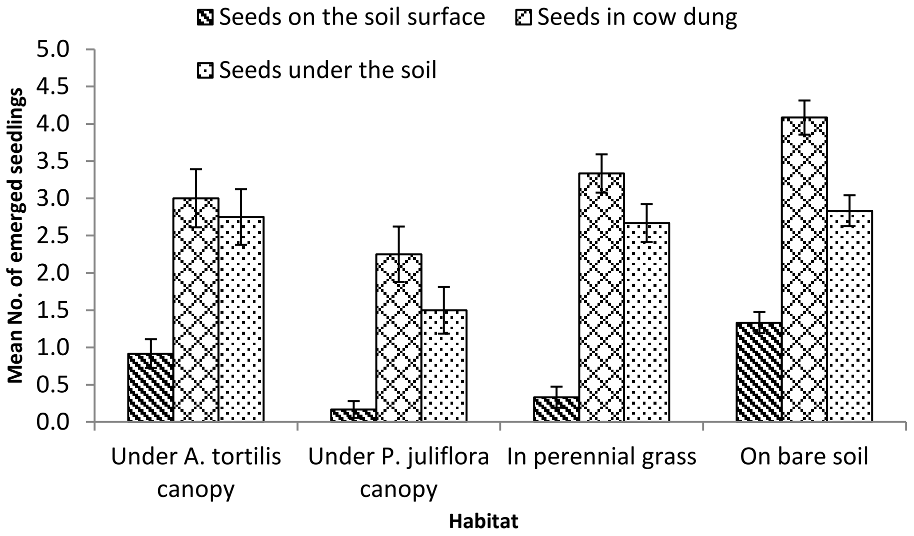

Figure 6.4: The mean number and standard errors of all emerged seedlings per habitat in soil with different treatments.

6.4.2 Effects of habitats and soil treatments on survival of seedlings

All the three factors, plant species ($F_{[1, 119]} = 243.8$, $P < 0.001$), habitat ($F_{[3, 119]} = 47.0$, $P < 0.001$) and treatment ($F_{[2, 119]} = 290.2$, $P < 0.001$) had very significant effects on the survival of seedlings. The interactions between species and treatment ($F_{[2, 119]} = 32.2$, $P < 0.001$), species and habitat ($F_{[3, 119]} = 14.4$, $P < 0.001$), treatment and habitat ($F_{[6, 119]} = 7.4$, $P < 0.001$) and between the three factors ($F_{[6, 119]} = 5.1$, $P < 0.001$), also had very significant effects on seedling survival. Like emergence, the mean number of *Prosopis juliflora* seedlings that survived in the different habitats under the three soil treatments was generally more than those of *Acacia tortilis* (figure 6.5). *Acacia tortilis* seedlings did not survive under *Prosopis juliflora* canopy in all the soil treatments and seedlings of both species did not survive in perennial grass where seeds were on the soil surface (figure 6.5).

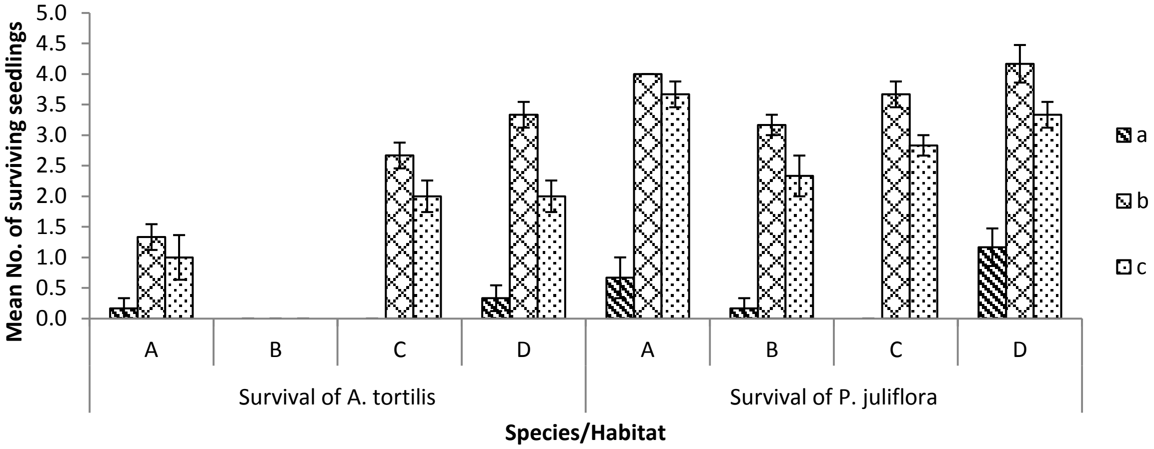

Figure 6.5: Mean survival and standard errors per habitat in each soil treatment for *Acacia tortilis* and *Prosopis juliflora* seedlings. No standard error bar means that the standard error mean was zero.

Key:

Defoliation treatments:	**Soil treatments:**
A = Not defoliated	a = Soil surface
B = Moderately defoliated	b = In cow dung
C = Heavily defoliated	c = Under soil
D = Total defoliation and dug soil	

The significant interaction effect between species and treatment implied that the impact of soil treatment on survival of seedlings varied depending on the species. Fisher's protected LSD test results (table 6.3) indicated that the number of *Prosopis juliflora* seedlings that survived were significantly more than those of *Acacia tortilis* in all the soil treatments. For both species, the survival of seedlings where seeds were on the soil surface was significantly less than in the other soil treatments and significantly more where seeds were in cow dung.

Table 6.3: Fisher's protected LSD test results for mean seedling survival in the treatment and species interactions. The means with different superscripts are significantly different.

Treatment	*A. tortilis*	*P. juliflora*
Seeds on the soil surface	0.13^{f}	0.50^{e}
Seeds in cow dung	1.83^{c}	3.75^{a}
Seeds under the soil	1.25^{d}	3.04^{b}

The significant interaction between species and habitat implied that the effect of habitat on survival of seedlings also varied depending on the species. Fisher's protected LSD test results (table 6.4) indicated that the number of seedlings of *Prosopis juliflora* that survived were significantly more than those of *Acacia tortilis* in all the habitats. There was a significant difference in survival of *Acacia tortilis* seedlings between all the habitats. However, survival was significantly less where seeds were planted under *Prosopis juliflora* canopy compared to other habitats. *Acacia tortilis* seedlings failed to survive to the end of the three months in any soil treatment under *Prosopis juliflora* canopy. The number of *Acacia tortilis* seedlings that survived where seeds were planted on bare soil in the open was significantly more compared to other habitats. In the case of *Prosopis juliflora,* survival of seedlings was also significantly less under *Prosopis juliflora* canopy. However, the difference in seedling survival for the seeds planted under *Acacia tortilis* canopy and those planted on bare soil was not significant.

Table 6.4: Fisher's protected LSD test results for mean seedling survival in the species and habitat interactions. The means with different superscripts are significantly different.

Habitat	*A. tortilis*	*P. juliflora*
Under *A. tortilis* canopy	1.56^c	2.78^a
Under *P. juliflora* canopy	0.00^e	1.63^c
In perennial grass	0.83^d	2.17^b
On bare soil	2.14^b	2.89^a

There was also a significant interaction effect between treatment and habitat, implying that the effect of the soil treatment given on survival of seedlings varied depending on the habitat. Fisher's protected LSD test results (Figure 6.6) showed that under *Acacia tortilis* canopy, seedling survival was significantly less for seeds on the soil surface, and significantly more for the seeds in cow dung. Under *Prosopis juliflora* canopy, seedling survival was significantly less for seeds on the soil surface, but not different for seeds in cow dung and those under the soil. In perennial grass, survival was zero for the seeds that were on the soil surface, but not different for the seeds in cow dung and those under the soil. On the bare soil, survival of seedlings was significantly less for seeds on the soil surface, and significantly more for those in the cow dung. For the seeds on the soil surface, survival of seedlings was zero in perennial grass and significantly less under *Prosopis juliflora* canopy. However, seedling survival was not different under *Acacia tortilis* canopy and on the bare soil. Survival of seedlings was significantly more on the bare soil and significantly less under *Prosopis juliflora* canopy for the seeds in cow dung. Seedling survival was significant under *Acacia tortilis* canopy compared to survival in perennial grass. For the seeds planted under the soil, seedling survival was also significantly less under *Prosopis juliflora* canopy, but not different for seeds under *Acacia tortilis* canopy and on the bare soil.

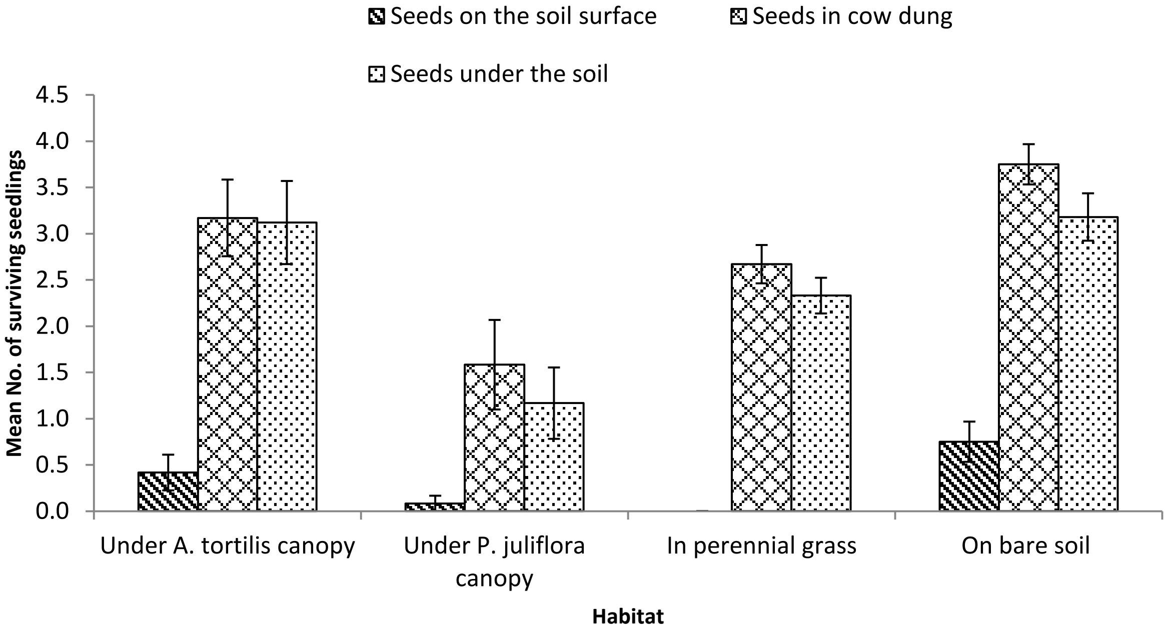

Figure 6.6: Mean survival and standard errors of all seedlings per habitat in soil with different treatments.

6.4.3 Effects of habitats and soil treatments on seedling biomass

All the three factors, plant species ($F_{[1, 119]} = 39.40$, $P < 0.001$), habitat ($F_{[3, 119]} = 38.45$, $P < 0.001$) and treatment ($F_{[2, 119]} = 93.25$, $P < 0.001$) had very significant effects on the biomass of the seedlings. The interaction between species and treatment ($F_{[2, 119]} = 7.0$, $P < 0.05$) and that between treatment and habitat ($F_{[6, 119]} = 5.94$, $P < 0.001$) also had significant effects on seedling biomass. However, the interaction between species and habitat ($F_{[3, 119]} = 2.29$, $P > 0.05$) and that among all the three factors had no effect on the biomass of the seedlings. Like emergence and survival, the biomass of *Prosopis juliflora* seedlings in the different habitats under the three soil treatments was generally higher than that of *Acacia tortilis* (figure 6.7).

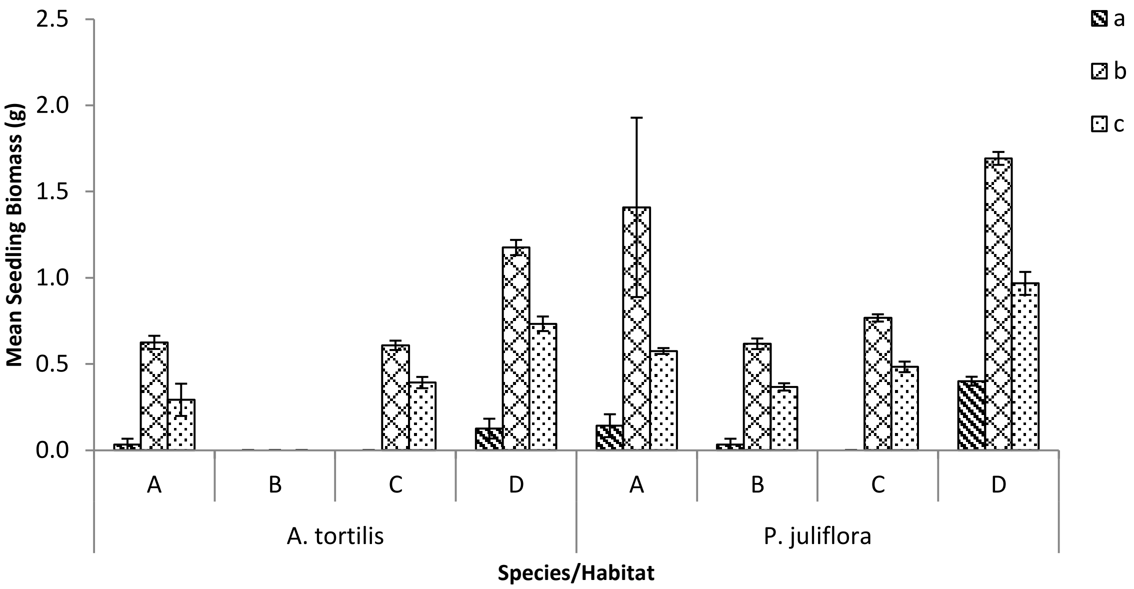

Figure 6.7: Mean biomass and standard errors per habitat in each soil treatment for *Acacia tortilis* and *Prosopis juliflora* seedlings

Key:

Defoliation treatments:	**Soil treatments:**
A = Not defoliated	a = Soil surface
B = Moderately defoliated	b = In cow dung
C = Heavily defoliated	c = Under soil
D = Total defoliation and dug soil	

The mean biomass of *Prosopis juliflora* was significantly higher compared to that of *Acacia tortilis* in all the habitats (table 6.5). On the other hand, the mean biomass of all the seedlings was significantly higher for seeds which were planted on bare soil and significantly lower for seeds which were planted under *Prosopis juliflora* canopy (table 6.5).

Table 6.5: The mean seedling biomass in the four habitats. The means with different superscripts are significantly different.

Habitat	Mean
Under *A. tortilis* canopy	0.513^{b}
Under *P. juliflora* canopy	0.169^{d}
In perennial grass	0.375^{c}
On bare soil	0.849^{a}

The significant interaction effect between species and treatment implied that the impact of soil treatment on the biomass of seedlings varied depending on the species in question. Fisher's protected LSD test results (table 6.6) indicated that the biomass of *Prosopis juliflora* seedlings was significantly higher than that of *Acacia tortilis* seedlings where seeds were in cow dung and also where seeds were planted under the soil. There was however no significant difference in biomass between seedlings of *Acacia tortilis* and those of *Prosopis juliflora* where seeds were on the soil surface. For both species, there were significant differences in biomass between all the soil treatments, but seedling biomass was significantly high for seeds that were in cow dung and significantly low for seeds that were on the soil surface.

Table 6.6: Fisher's protected LSD test results for mean seedling biomass in the treatment and species interactions. The means with different superscripts are significantly different.

Treatment	*A. tortilis*	*P. juliflora*
Seeds on the soil surface	0.040^{d}	0.144^{d}
Seeds in cow dung	0.602^{b}	1.121^{a}
Seeds under the soil	0.354^{c}	0.598^{b}

There was also a significant interaction effect between treatment and habitat, implying that the effect of the soil treatment on biomass of seedlings varied with the habitat. Under *Acacia tortilis* canopy, seedling biomass was significantly low for seeds on the soil surface, but not different for the seeds in cow dung and those under the soil (figure 6.8). On the bare soil, seedling biomass was significantly low for the seeds on the soil surface and significantly higher for seeds in cow dung than those under the soil. Since none of the seedlings that were on the soil surface survived for the three months in the perennial grass, biomass was zero in this particular habitat. Under *Prosopis juliflora* canopy, seedling biomass was significantly low for the seeds on the soil surface compared to those given the other treatments. However, seedling biomass for the seeds in cow dung and those under the soil was not significantly different. For the seeds on the soil surface, seedling biomass was zero in perennial grass, significantly low under *Prosopis juliflora,* but not different under *Acacia tortilis* compared to bare soil. For the seeds in cow dung and those under the soil, seedling biomass was significantly low under *Prosopis juliflora* canopy, significantly higher under *Acacia tortilis* canopy than in perennial grass and significantly high on bare soil.

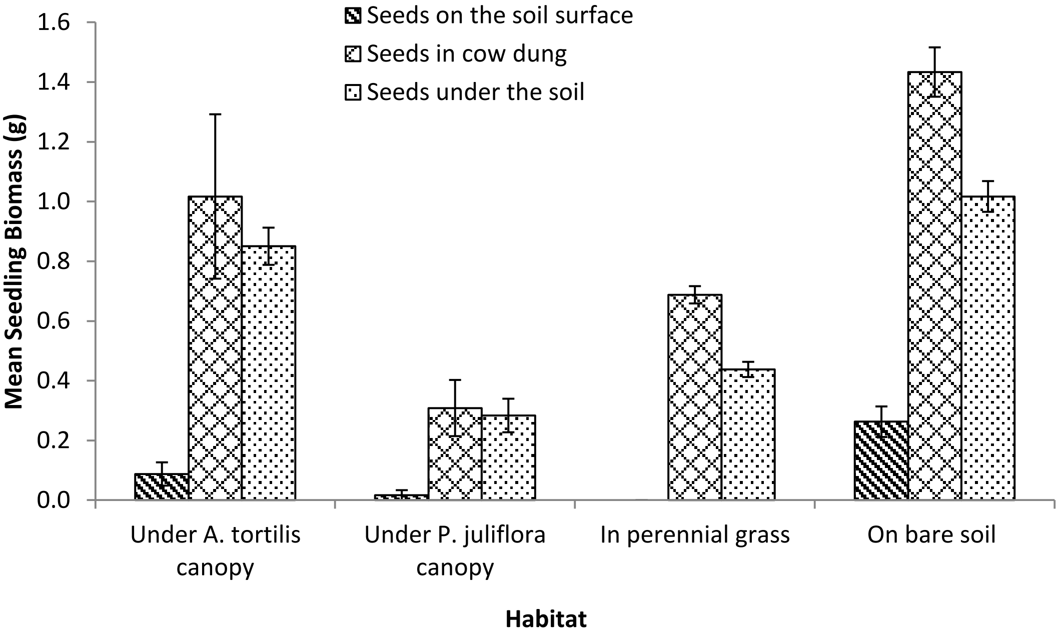

Figure 6.8: Mean biomass and standard errors of all seedlings per habitat in the different soil treatments.

6.5 Discussion

The response of different plant species to different environmental factors can vary greatly depending on the adaptations of the plant. In the case of trees, the life-history stages of a given species may also not respond similarly to the same environmental factors. The most important stage in the life-history of a tree is the seedling establishment stage (Sankaran *et al.* (2004). The first stage in the life-history of a tree is germination which is marked by appearance of a radical. Seedling establishment stage follows germination and ends when the seedling has exhausted the food reserves stored in the seed (Weitbrecht & Leubner-Metzger, 2011). The seedling stage is critically important in arid and semi-arid regions since survival of seedlings after drought periods determines the presence of woody species (Breshears & Barnes, 1999).

Seedlings of different plant species growing in a similar environment may or may not show variation in their response to the existing environmental factors depending on their adaptations. This variation in seedling adaptations results to differences in their competitive abilities, and may determine their persistence and abundance in plant communities (Peltzer & Kochy, 2001). The current study determined and compared the emergence, survival and biomass accumulation of *Acacia tortilis* and *Prosopis juliflora* planted in similar habitats and soil treatments.

6.5.1 Emergence of seedlings

Germination of seeds requires a moist environment and favourable temperatures which vary in different habitat types and soil treatments as shown by Loth *et al.* (2005). Moreover, different plant species require different amounts of moisture and temperatures for them to germinate. In this study, the number of seedlings that emerged was an indicator of the number of seeds that successfully germinated and it varied with the habitat type, soil treatment and plant species. The number of seedlings that emerged was few where seeds were on the soil surface compared to the other treatments for both *Acacia tortilis* and *Prosopis juliflora*. There was no significant difference in seedling emergence between the two species in this soil treatment, implying that the conditions on the soil surface were not conducive for germination of either species. This was probably because of the high temperatures at the soil surface since the seeds were exposed to the hot sun, drying and killing them.

Acacia tortilis seedlings did not emerge under *Prosopis juliflora* canopy and in perennial grass for the seeds on the soil surface. Emergence of *Prosopis juliflora* seedlings was significantly less under *Prosopis juliflora* and in perennial grass, but not different for the seeds planted under *Acacia tortilis* and on bare soil. The moisture level and temperature conditions under *Prosopis juliflora* and in perennial grass were probably not favourable for germination of both species, but more so for *Acacia tortilis*. Established grasses share resources such as moisture at the same level as woody species seedlings (Chirara *et al.* 2002), reducing the moisture that is necessary for germination. The grass in this study did not enhance germination even though some amount of vegetation cover enhances retention of seed moisture (Singh *et al.* 2004). This means the cover was more than the ideal, increasing competition for moisture. Other than the low moisture conditions under *Prosopis juliflora* being unfavourable, *Prosopis* species also contain chemicals which according to Pasiecznik *et al.* (2001), prevent the germination of other plant species. Getachew *et al.* (2012) showed that the soil under *Prosopis juliflora* canopy inhibits germination of *Acacia tortilis* seeds. In this study, lack of moisture and allelopathy could have caused the low and non-germination of *Prosopis juliflora* and *Acacia tortilis* respectively under *Prosopis juliflora* canopy.

The seeds that were planted in soil and those in cow dung were protected from the direct heat of the sun and thus germinated more successfully. However, besides protection from the sun, cow dung provided the required water-holding environment (Loth *et al.* 2005) which is necessary for germination, enhancing emergence of more seedlings. However, few seedlings emerged under *Prosopis juliflora* and more on bare soil even for seeds under these soil treatments. Seeds planted on bare soil encountered no competition for resources from perennial grasses and probably no allelopathic effects from *Prosopis juliflora*. Loth *et al.* (2005) found that seeds buried in soil and those covered with elephant dung germinated more readily than those on the soil surface. The current study concurs with this finding for the seeds on the soil surface, but seedling emergence was more for the seeds in cow dung than those planted in soil. Loth *et al.* (2005) also found germination of *Acacia tortilis* seeds to be less under its canopy than its germination on bare soil and in perennial grass. This study also concurs with these findings, but emergence of *Acacia tortilis* seedlings was less under *Prosopis juliflora* canopy than under its own canopy. However, the study gives results that contradict those of Smith & Shackleton (1988) who found *Acacia tortilis* seed germination to be more under canopies than in the open areas.

6.5.2 Survival of seedlings

The results of this study indicate that seedling survival not only varied depending on species, but also on the soil treatment and the habitat type. In all the habitats and soil treatments, more seedlings of *Prosopis juliflora* survived compared to those of *Acacia tortilis*. *Prosopis* species are fast growing (Pasiecznik *et al.* 2001; Shiferaw *et al.* 2004), can grow well in a wide variety of environments (Pasiecznik *et al.* 2001) and outcompete native species (Raghubanshi *et al.* 2005). Moreover, they have long taproots (Felker *et al.* 1983); Chapter 5 of this study) which enable them to reach for water deeper in the soil compared to *Acacia tortilis* seedlings. *Acacia tortilis* seedlings did not survive under *Prosopis juliflora* canopy in all the treatments. The soil under *Prosopis juliflora* canopy was relatively dry and hard. This could have inhibited the survival of *Acacia tortilis* seedlings due to difficulty in penetration of the taproots and less moisture. Indeed, water availability was found to be one of the main determinants of *Acacia tortilis* seeding survival (Rohner and Ward, 1999). In addition, the dense canopy of *Prosopis juliflora* reduced the amount of light reaching the *Acacia tortilis* seedlings, inhibiting survival. Getachew *et al.* (2012) found that low light under *Prosopis juliflora* canopy inhibited plant species survival. Some *Prosopis juliflora* seedlings survived under its canopy, but survival was significantly less compared to other habitat types. A study by Kahi *et al.* (2009) in Njemps Flats range in Kenya found that herbaceous cover was less under *Prosopis juliflora* than under *Acacia tortilis* canopy, implying that the conditions under the former species suppressed herbaceous growth. The findings of another study in Ethiopia by Getachew *et al.* (2012) showed that the soil under *Prosopis juliflora* inhibited both germination and growth of *Acacia tortilis*. Thus, allelopathy could also have inhibited seedling survival under *Prosopis juliflora* canopy.

Although some *Prosopis juliflora* and *Acacia tortilis* seedlings emerged from the seeds on the soil surface in perennial grass, they failed to survive to the end of the three months. Herbaceous vegetation is known to compete with woody plant species seedlings for resources and thus suppress their survival (Chirara *et al.* 2002; Chirara & Dijkman 2002; Chapter 5 of this study). Non-survival of seedlings in perennial grass could have been due to competition of the seedlings with the already established grass. In both the perennial grasses and under *Prosopis juliflora* canopy, seedling survival was the same for the seeds in cow dung and those planted in soil, though less compared to the other habitats. Cow dung contains the necessary nutrients (Coughenour & Detling, 1986) and a water-holding environment (Loth et al. 2005) which aids in seedling survival. This suggests that the effect of competition and allelopathy in perennial grass and under *Prosopis juliflora* canopy respectively were more important than the positive effect of cow dung.

However, under *Acacia tortilis* canopy and on bare soil, seedling survival was more for the seeds that were in cow dung, implying that the additional nutrients and/or retention of moisture by cow dung could have enhanced seedling survival. Peltzer & Kochy (2001) carried out a study in Canada and found resource availability to be up to fivefold higher in plots that had no vegetation compared to those with vegetation. There was also no competition for resources in the absence of herbaceous vegetation in bare soil like in the perennial grasses. Some researchers such as Belsky *et al.* (1992) have found that *Acacia tortilis* increases soil fertility and hence productivity. Moreover, fertilization by cow dung could have enhanced seedling survival both under *Acacia tortilis* canopy and on bare soil. Survival of *Acacia tortilis* was highest on bare soil, more under its own canopy than in the perennial grasses and none under *Prosopis juliflora* canopy. However, survival of *Prosopis juliflora* seedlings was more under *Acacia tortilis* canopy and on bare soil, less in perennial grass but least under its own canopy.

6.5.3 Biomass of seedlings

Like emergence and survival, seedling biomass also varied depending on the species, the soil treatment and the habitat type. The mean biomass of *Prosopis juliflora* was higher than that of *Acacia tortilis* in all the habitats and in all treatments except where seeds were on the soil surface. *Prosopis juliflora* seedlings have long taproots (Chapter 5 of this study) which absorbed more moisture and nutrients from the soil unlike those of *Acacia tortilis*. This resulted to high biomass accumulation in *Prosopis juliflora* compared to *Acacia tortilis*. Felker *et al.* (1983) also found *Prosopis juliflora* to have a long taproot that increased its water use efficiency. There was low accumulation of biomass for the few surviving seedlings of both species for the seeds on the soil surface. This was because of the high temperatures at the soil surface, poor anchoring of roots, low moisture content and nutrient level especially for *Acacia tortilis* seedlings with shorter taproots (Chapter 5 of this study) compared to those of *Prosopis juliflora.*

The seedlings of both species had the highest biomass for the seeds that were in cow dung. The increased nutrients in cow dung probably increased seedling growth and enhanced biomass accumulation. Depending on the patterns of dung deposition, livestock grazing may result to low or high soil nutrients (Grellier *et al.* 2012). Thus, besides herbivores dispersing viable woody plant seeds (Tjelele *et al.* 2012), they can also increase seedling biomass due to enhanced nutrients from their dung. The findings of this study concur with the above researchers, but the effect of additional nutrients from cow dung depended on the species and the site characteristic. Thus, it was not applicable for *Acacia tortilis* under *Prosopis juliflora* canopy, implying that the effect of the canopy was more important than that of cow dung. The results point to the expected seedling response caused by additional nutrients due to deposition of dung by livestock in different habitats. The results also show that *Acacia tortilis* is a slow-growing species, unlike *Prosopis juliflora* which grew faster in different habitats and soil treatments.

In all the soil treatments, biomass accumulation of seedlings was lowest under *Prosopis juliflora* canopy and highest on bare soil and under *Acacia tortilis* canopy. Kahi *et al.* (2009) found significantly low organic carbon and total nitrogen in soils under *Prosopis juliflora* compared to those under *Acacia tortilis* canopy. Although the soils under these canopies were not analyzed in this study, the soil under *Prosopis juliflora* was drier and hard based on observation. These conditions would make it more difficult for penetration of seedling taproots, implying less moisture and nutrients for the seedlings and hence slower accumulation of biomass. Besides, *Prosopis juliflora* is known to release chemicals which inhibit growth of many plants (e.g. Pasiecznik *et al.* 2001; Getachew *et al.* 2012). Indeed, Getachew *et al.* (2012) showed that soils under *Prosopis juliflora* canopy inhibited the growth of *Acacia tortilis*.

Under *Acacia tortilis* canopy, biomass accumulation was the same for seeds covered with cow dung and those buried in soil. Belsky (1992) found soils under tree and shrub canopies to be rich in organic matter, total and available N, Ca, K and P than soils in the open spaces. In particular, *Acacia tortilis* was found to increase soil fertility and enhance herbaceous quality and productivity. This could explain the high seedling biomass under *Acacia tortilis* canopy even without additional nutrients from cow dung. On bare soil, seedling biomass was highest for seeds in cow dung than those in soil. This implied that additional nutrients from cow dung enhanced biomass accumulation on bare soil. Although Peltzer & Kochy (2001) found resource availability to be higher in bare plots, this study shows that additional nutrients facilitated seedling biomass in bare plots. This means that the existing nutrient level in the bare soil was less than the optimum quantities.

Reduced light levels under canopies of trees may affect performance of seedlings in terms of survival and growth. Some researchers e.g. Gomez-Aparicio *et al.* (2005) found that tree canopies enhanced seed germination as well as seedling survival and growth. Other researchers e.g. Getachew *et al*. (2012) found that tree canopies inhibited plants growth in the early stages of development. Thus, the effect of tree canopies on the performance of plant species varied depending on the study area, the canopy species and the particular species growing underneath the canopies. According to Smith & Shackleton (1988), shading favoured both the establishment and growth of *Acacia tortilis* seedlings compared to their performance in the open areas. In Ethiopia, Getachew *et al*. (2012) showed that *Prosopis juliflora* canopy inhibited the germination and growth of *Acacia tortilis.* In Tanzania, Loth *et al.* (2005) showed that germination of *Acacia tortilis* was less under its canopy compared to its germination on bare soil and in perennial grass. Another study by Kahi *et al.* (2009) in Njemps Flats range in Kenya found herbaceous vegetation to be more in the open areas than under the canopies of *Prosopis juliflora* and *Acacia tortilis*. However, herbaceous vegetation was more under *Acacia tortilis* canopy than under *Prosopis juliflora* canopy. This implied that conditions under *Prosopis juliflora* canopy suppressed the growth of herbaceous vegetation more than those under *Acacia tortilis* canopy.

6.6 Conclusion

This study determined and compared the emergence, survival and biomass of *Acacia tortilis* and *Prosopis juliflora* seedlings planted in similar habitats and soil treatments. Competition with perennial grass and unfavourable conditions on the soil surface led to non-survival of both *Acacia tortilis* and *Prosopis juliflora* seedlings. Allelopathic effects under *Prosopis juliflora* canopy killed *Acacia tortilis* seedlings, unlike *Prosopis juliflora seedlings* which survived under *Acacia tortilis* canopy. Seedlings of both species emerged most readily, survived and accumulated biomass faster on bare soil and when covered with cow dung which provided favourable conditions. This was unlike under *Prosopis juliflora* canopy where biomass accumulation was lowest.

Thus, emergence, survival and biomass accumulation depended on habitat type, soil treatment and the species involved. In similar habitats and soil conditions, *Prosopis juliflora* was more successful than *Acacia tortilis* as depicted by its relatively high emergence, survival and biomass in all the habitats and most of the soil treatments.

CHAPTER SEVEN: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1 General discussions

The vegetation structure in upper Tana River varied with the cross-sectional floodplain gradient and across the land use types as reported in chapter 3. The density of non-woody species (forbs and perennial grasses) was highest in the floodplain. However, the same did not apply to the woody plant species (shrubs and trees) whose density was not significantly different between inside and outside the floodplain. The density of all the vegetation was expected to be higher inside the floodplain than outside since flood water positively affects plant regeneration, establishment and growth (Resh *et al.* 1988; Mworia *et al.* 2011). However, anthropogenic disturbances related to crop farming in the floodplain reduced the overall density of woody plant species as well as the overall basal area and canopy cover of tree species.

Outside the floodplain, droughts can reduce the abundance and diversity of plants, which are dependent on natural precipitation for survival. The same can happen inside the floodplain even though nutrient and moisture conditions are more favourable because of reduced river flows and peak flows. In River Tana, construction of mega dams upstream has reduced flood quantity and altered peak flows (Maingi & Marsh, 2002). Reduction in flood water affects germination and establishment of plants because critical minimum flooding levels and frequency are necessary to permit successful germination and establishment of woody plant species (Hughes, 1988). The reduced water and nutrients negatively impacts crop farming and vegetation downstream. This is because sufficient moisture is necessary for successful germination and establishment of seedlings (Rohner & Ward, 1999; Stave *et al*. 2006), whether inside or outside the floodplain.

Acacia tortilis and *Prosopis juliflora* were used as good indicators of the differences in plant community structure. The density of *Prosopis juliflora* was higher in the floodplain than outside the floodplain. However, it had a high regeneration potential in irrigated agricultural areas. This was unlike *Acacia tortilis* and other indigenous species, making *Prosopis juliflora* a serious threat to native species. This invasive plant generally thrived well in different environmental conditions, and its regeneration was not affected much by anthropogenic disturbances, such as weeding. Indeed, a number of *Prosopis juliflora* seedlings and saplings thrived well under some mature *Acacia tortilis* trees inside the floodplain in Bura East. However, no seedlings or saplings of *Acacia tortilis* were found growing under any *Prosopis juliflora* tree anywhere in the study area.

Since anthropogenic disturbances cause alterations in species composition and diversity, and increase invasion (Kalema & Witkowski, 2012; Davis & Pelsor, 2001; Angassa, 2014), the indigenous plant species inside the floodplain, in livestock grazing and irrigated agricultural areas would be most affected. This probably explains why the density of woody species in the floodplain, which was highly invaded by *Prosopis juliflora*, was not different compared to that outside the floodplain where conditions were less favourable. It also explains why irrigated agricultural areas, which were highly disturbed, were also highly invaded by *Prosopis juliflora* and poor in woody plant species. On the other hand, wildlife conservation areas which were the least disturbed, had most tree species and were least invaded, although the mean basal area of the invading species was significantly high. Although livestock grazing areas had the highest density of woody species, a reduction in livestock forage is expected if *Prosopis juliflora* dominates the rangelands, which will lead to a decline in livestock numbers. This is because in plots which were dominated by *Prosopis juliflora*, no other woody or non-woody species grew underneath its canopy. This concurs with the findings of Angassa (2014), who found that invasion in rangelands led to reduction in livestock forage and a decline in livestock numbers.

Soil properties had a strong bearing on the distribution of plant species both inside and outside the floodplain (Chapter 4). The floodplain had more nutrients and moisture which made it more fertile and therefore favourable for plant growth compared to areas outside the floodplain. The significantly higher bulk density outside the floodplain was due to trampling by livestock, an observation that has been made in other studies (Tate *et al.* 2004; Kamau 2004; Mworia *et al.* 2008; Zhou *et al.* 2010; Pulido *et al.* 2016). Soils provide the necessary nutrients and moisture required by plants for growth and regeneration and hence influence their composition and distribution. Soils with low bulk density are easily penetrated by plant roots, ensuring absorption of nutrients and moisture, which favours their establishment, growth and survival. The variation explained by soil variables was higher outside the floodplain than inside, and higher in wildlife conservation areas than in livestock grazing and irrigated agricultural areas. The high unexplained variation by the soil variables in the floodplain, in livestock grazing and irrigated agricultural areas was attributed to human and livestock disturbances. Hence, in wildlife conservation areas where disturbance was minimal, the percentage variation explained by the soil variables was very high.

The invasive plant *Prosopis juliflora* was found inside and outside the floodplain in all the land use types in varied soil conditions. Invasive plants can thrive well in very dry as well as in salty environments where indigenous vegetation cannot survive (Mahmood *et al*. 2016; Saraswathi *et al.* 2016). They are more competitive for resources compared to indigenous plants and can displace them (Tilman, 1997; Davis *et al.* 2000; kolb *et al.* 2002; Muturi *et al.* 2009; Getachew *et al.* 2012). It is therefore necessary to control the density of *Prosopis juliflora* as it is a threat to the indigenous plant species.

The main human activities, livestock grazing and cultivation, affected plant regeneration and life-history dynamics of both *Acacia tortilis* and *Prosopis juliflora* seedlings (Chapter 5). *Prosopis juliflora* performed better than *Acacia tortilis,* and better inside than outside the floodplain. Thus, significantly more invasion occurs in the floodplain which has more water and nutrients as shown in chapter 4 of this thesis. Besides the floodplain, other favourable areas that promoted the spread of *Prosopis juliflora* in Tana River County are irrigated farmlands and overgrazed areas. This was shown by the significantly higher emergence, survival and growth of *Prosopis juliflora* compared to *Acacia tortilis* in cultivated plots and in plots where herbaceous vegetation was heavily defoliated. Displacement of *Acacia tortilis* by *Prosopis juliflora* probably starts by limiting germination/emergence and survival before subsequently inhibiting growth. The synergistic effects of the favourable conditions in the floodplain, cultivation and heavy defoliation of herbaceous vegetation will inevitably increase proliferation of the invading plant species.

Site characteristics and soil treatments also affected plant regeneration and life-history dynamics of both *Acacia tortilis* and *Prosopis juliflora* seedlings (Chapter 6). Generally, more seedlings of both species emerged, survived, and accumulated more biomass on bare soil and under *Acacia tortilis* canopy than in perennial grass and under *Prosopis juliflora* canopy. Very few seeds that were deposited on the soil surface emerged and fewer survived.

For the few seeds that survived, biomass was lower compared to other soil treatments. More seedlings emerged, survived and accumulated more biomass where seeds were in cow dung which prevented direct exposure to the hot sun and provided additional nutrients. The synergistic effect of a conducive site characteristic and a favourable soil treatment enhanced seedling emergence, survival and biomass accumulation. Thus, more seedlings emerged, survived and accumulated more biomass on bare soil and under *Acacia tortilis* canopy for the seeds that were in cow dung. On the other hand, fewer seedlings emerged, survived and accumulated less biomass under *Prosopis juliflora* canopy for the seeds deposited on the soil surface. In perennial grass, few seedlings of both species emerged, but none survived to the end of the study period. The established perennial grass out-competed the woody seedlings, denying them adequate nutrients and moisture for survival. Under all the site characteristics and all the soil treatments except where seeds were deposited on the soil surface, *Prosopis juliflora* performed better than *Acacia tortilis* in terms of emergence, survival and biomass accumulation.

In semi-arid areas, where rains are erratic, displacement of indigenous plant species by *Prosopis juliflora* is probably due to their limited capacity to emerge, survive and grow compared to *Prosopis juliflora*. For example, the emergence of *Acacia tortilis* is limited probably because of having a highly variable dormancy period, inadequate moisture to break the testa, poor viability of seeds produced in certain seasons of the year as well as predation of seeds and seedlings by insects and goats. The shorter roots of *Acacia tortilis* limit survival and growth due to inability to access and absorb sufficient water and nutrients. On the other hand, *Prosopis juliflora* produces many viable seeds, which germinate and grow rapidly in a wider range of environmental conditions once dormancy is broken. The survival and growth of *Prosopis juliflora* is enhanced by its long tap roots and secondary roots which ensure efficient absorption of water and nutrients. These variations, and the allelopathic effects of *Prosopic juliflora*, help explain the relatively high abundance and persistence of the invader compared to *Acacia tortilis* and other indigenous plants in semi-arid areas with shallow ground water table.

Overall, vegetation community composition and structure was influenced by the seasonal floods, invasion by *Prosopis juliflora* and human activities. The floods are influenced by climate variability and construction of dams which support irrigation based farming in arid and semi-arid regions, but also influence seasonal floods by reducing peak flows, which prevents flooding. The effect of large dams constructed along Tana River basin in the 1980s has been to reduce water flow and silt deposition upon which flood-recession agriculture depends downstream. This, coupled with the effects of climate variability, human activities and *Prosopis* invasion could have synergistic effects, seriously affecting the composition of indigenous plant species. The species found only inside the floodplain at low densities are most at risk because the density of *Prosopis juliflora* is significantly high and any change in flooding regimes will negatively impact their establishment and survival. Droughts affect germination of seeds and establishment of seedlings as well as their growth, especially outside the floodplain where vegetation is dependent on natural precipitation. However, plant species which had high densities outside the floodplain will survive if they are not over-exploited for firewood, charcoal production and construction purposes.

7.2 Conclusions

The results of the study have shown that;

The population structure of vegetation varied with the cross-sectional floodplain gradient as well as on the land use practices in the study area. The overall density of non-woody vegetation was significantly higher inside the floodplain, unlike the woody vegetation where there was no difference between the density in the floodplain and in areas outside the floodplain. The overall basal area and canopy cover of trees were significantly higher outside the floodplain. There was no significant difference in the density of both tree and shrub species between land use types. However, there were differences in the canopy cover, basal area and density of specific species that were found both outside the floodplain and inside and among the land use types. Among these species was *Prosopis juliflora* whose mean basal area of was significantly high in wildlife conservation areas. This invasive plant contributed the highest to IV 200 in all the land use types, but the contribution was highest in irrigated agricultural areas.

Variation in the soil properties was considerable in the study area, especially between areas inside and those outside the floodplain, with significant differences in some cases. CCA analysis showed that the distribution of the tree species was influenced by the soil properties, some significantly. The variation that could not be explained by the soil properties was higher inside the floodplain. This was attributed to the natural and anthropogenic disturbances in the floodplain as possible factors that also influenced tree species distribution besides the soil properties. The variation explained by the soil properties was highest in wildlife conservation areas, which were least disturbed.

Variation in soil properties and moisture conditions, herbaceous defoliation and cultivation all affected both *Prosopis juliflora* and *Acacia tortilis* in the early stages of development. The potential for regeneration of woody species was higher inside the floodplain, in plots where herbaceous vegetation was heavily defoliated and in cultivated plots. However, *Prosopis juliflora* regenerated faster than *Acacia tortilis*, in all the cases. The areas that favour the spread of *Prosopis juliflora* in Tana River County are the floodplain, cultivated farmlands and overgrazed areas. Consequently, the effect of grazing and crop farming in the floodplain will greatly increase the proliferation of *Prosopis juliflora.*

In similar site characteristics and soil treatments, *Prosopis juliflora* performed better than *Acacia tortilis* in terms of seedling emergence, survival and biomass accumulation. The exception was for the seeds that were placed on top of the soil where there was no significant difference between *Prosopis juliflora* and *Acacia tortilis*. It was worth noting that whereas seedlings of *Acacia tortilis* did not survive under *Prosopis juliflora* canopy, those of *Prosopis juliflora* survived under *Acacia tortilis* canopy. This indicated the advantage that the invasive plant had over *Acacia tortilis,* and by extention other indigenous plant species. There is a tendency for *Prosopis juliflora* to suppress other species wherever it is well established.

7.3 Recommendations

There is no single method or strategy of controlling invasive plant species. However, doing nothing to control invasive species can create a costly management crisis. A combination of natural processes and human activities are promoting the spread of *P. juliflora* in the floodplains of Tana River. Recommendations are herein given for further research, conservation/management actions and policy interventions based on the findings of this research.

7.3.1 Further research

a. An experimental study should be conducted that involves planting seeds of woody species along a moisture gradient from the floodplain to areas outside the floodplain so as to determine the optimum moisture conditions for seed germination and seedling survival.

b. The seeds of *Acacia tortilis* used in this study were obtained from Kenya Agricultural Research Institute in Muguga. Ideally, the seeds should be obtained from the study area for further study.

c. An experimental study similar to the one of Chapter 6, which was done outside the floodplain, should be conducted inside the floodplain.

d. The cow dung used as one of the soil treatments in Chapter 6 was transported from the cow sheds for use in the field experiment. The seeds should also be planted in cow dung that is deposited in the field under similar site characteristics.

e. The seed load in mammalian herbivore dung should be assessed so as to evaluate the role of livestock and wildlife in the dispersal of *Prosopis juliflora* and *Acacia tortilis.*

7.3.2 Conservation/Management actions

a. Crop farmers should be sensitized on the high cost of controlling mature *Prosopis juliflora* and the need to uproot its seedlings while selectively retaining and planting those of indigenous plants. Incentives should be given to those who comply.

b. Specific areas should be designated for shallow wells, sub-surface dams and earth pans to reduce grazing pressure of livestock inside the floodplain. This will reduce invasion and fights between pastoralists and crop farmers over damages to crops in the floodplain.

c. Residents should be encouraged to use *Prosopis juliflora* trees for firewood, charcoal and domestic feed and save *Acacia tortilis.*

d. Residents should be encouraged to collect *Prosopis juliflora* pods for possible production of supplements for their livestock.

e. Instead of fallowing farms to regain fertility, compost and farmyard manure, planting leguminous crops and practicing crop rotation can improve soil fertility in farmlands. This will ensure that farmers consistently uproot *Prosopis juliflora* seedlings instead of allowing them to become a forest.

7.3.3 Policy intervention

a. A thermal power station that uses *Prosopis juliflora* should be set up in upper Tana River in addition to charcoal production using the plant. These activities will provide employment to the local community and act as an incentive for them to reduce proliferation of the invader species.

b. Pastoral communities should be encouraged to keep fewer animals and adopt a grazing plan so as to avoid overgrazing as well as opt for other income generating ventures.

c. Dam construction along the Tana River should take into account the potential for proliferation of invasive plant species and compensate communities for loss of grazing land and flood-recession farming in downstream areas.

References

Abdelfattah, M. A. (2009). Land degradation indicators and management options in the desert environment of Abu Dhabi, United Arab Emirates. *Soil Survey Horizons*, 50:3–10.

Adel, M. N., Mehrdad, G. D., Mohaddeseh, S. P., Javad, J., Javad, S. K. and Roghayeh, J. (2017). Relationship of soil physical and chemical properties with ecological species groups in Pinus taeda plantation in northern Iran. *Biodiversitas*, 18(1):422-426.

Adger, W. N., Huq, S., Brown, K., Conway, D. and Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies*, 3(3):179-195.

Agea, J. G., Obua, J. and Ogwal J. J. (2010). Status of forests in Uganda. *African Journal of Ecology*, 48(4):853-859.

Andersen, G. L., Krzywinski, K., Gjessing, H. K. and Pierce, R. H. (2015). Seed viability and germination success of *Acacia tortilis* along land-use and aridity gradients in the Eastern Sahara. *Journal of Ecology and Evolution*, 29:6(1):256-266.

Andersen, G. L. and Krzywinski, K. (2007). Mortality, recruitment and change of desert tree populations in a hyper-arid environment. PLoS One 2:e208.

Andersen, G. L., Krzywinski, K., Talib, M., Saadallah, A. E. M., Hobbs, J. J. and Pierce, R. H. (2014). Traditional nomadic tending of trees in the Red Sea Hills. *Journal of Arid Environments*, 106: 36-44.

Angassa, A. (2014). Effects of grazing intensity and bush encroachment on herbaceous species and rangeland condition in Southern Ethiopia. Land Degradation & Development. 25. DOI:10.1002/ldr.2160.

Amoros C. and Bornette G. (2002). Connectivity and biocomplexity in waterbodies of riverine floodplains. *Fresh water Biology*, 47:761-776.

Archer, S. and Smeins, F. E. (1991). Ecosystem-level processes. In: Heitschmidt, R.K., Stuth, J.W. (Eds.), Grazing Management. An Ecological Perspective. Timber Press, Portland, Oregon, USA, pp. 109–139.

Archer, S. (1994). Woody plant encroachment into southwestern grassland savannas: rates, patterns and proximate causes. In: Vavra, M., Laycock, W.A., Pieper, R.D. (Eds.), Ecological Implications of Livestock Herbivory in the West. Society of Range Management, Denver, Colorado, USA, pp. 13–68.

Archer, S. (1995). Herbivore mediation of grass–woody plant interactions. *Tropical Grasslands*, 29: 218–235.

Azarnivand, H., Mohammad, A. Z. C and Lyla, K. (2014). Effective environmental factors on plant Distribution in Sennan Rangelands of Iran. International Conference on Biological, Environment and Food Engineering in Bali (Indonesia).

Azazi, E. L., Sayed, E. L., Sourour, M. M., Belal, A. H. and Khalifa, E. A. (2013). Improving Acacia tortilis seed germination by breaking dormancy treatment. *International Journal of Advanced Biological Research*, 3:103-109.

Belsky, A. J. (1992). Effects of Trees on Nutritional Quality of Understorey Gramineous Forage in Tropical Savannas. *Tropical Grasslands,* 26(1): 12-20.

Belsky, A. J., Mwonga, S. M., Amundson, R. G., Duxbury, J. M. and Ali, A. R. (1993). Comparative Effects of Isolated Trees on their Undercanopy Environments in High-rainfall and Low-rainfall Savannas. *Journal of Applied Ecology,* 30(1): 143-155.

Bever, J. D., Ian, A. D., Jose, M. F., John, K., Mari, M., Matthias, R., *et al*. (2010). "Rooting Theories of Plant Community Ecology in Microbial Interactions." *Trends in Ecology and Evoloution*, 25: 468–478.

Binggeli, P. (2001). Human dimensions of invasive woody plants. In: McNeely J. A. (ed). The great reshuffling: human dimensions of invasive alien species. IUCN, Gland.

Black, C. A. (1986). Methods of Soil Analysis. American Society of Agronomy, Madison, Wiscousin, USA.

Breshears, D. D. and Barnes, F. J. (1999). Interrelationships between plant functional types and soil moisture heterogeinity for semiarid landscapes within grasslands forest continuum: a unified conceptual model. *Landscape Ecology,* 14: 465–478.

Brooks, M. L. C. M., D'Antonio, D. M., Richardson, J. B., Grace, J. E., Keeley, J. M., DiTomaso, R. J. *et al*. (2004). Effects of invasive alien plants on fire regimes. *BioScience,* 54: 677-688.

Brown, J. R., Scanlan, J. C. and Mcivor, J. G. (1998). Competition by herbs as a limiting factor in shrub invasion of grassland: a test with different growth forms. *Journal of Vegetation Science,* 9: 829-836.

Caldeira, M. C., Ines, I., Carla, N., Miguel, N. B., Xavier, L., Andreia, M. and Joao, S. P. (2014). Direct and indirect effects of tree canopy facilitation in recruitment of Mediterranean oaks. *Journal of Applied Ecology,* 51: 349-358.

Child, M. F., Sue, J. M., Richard, W. J. D., Marisa, K. L., James, P., Tesa, N. H. *et al.* (2010). Tree-grass coexistence in a flood-disturbed, semi-arid savanna system. *Landscape Ecology,* 25:315-326.

Chipman, S. J. and Johnson, E. A. (2002). Understorey vascular plant species diversity in mixed wood boreal forest of western Canada. *Ecological Applications,* 12(2): 588-601.

Chirara, C., Frost, P. G. H. and Gwarazimba, V. E. E. (1999). Grass defoliation affecting survival and growth of seedlings of Acacia karroo, an encroaching species in southwestern Zimbabwe. *African Journal of Range and Forage Science*, 15*:* 41-47.

Chirara, C. and Dijkman, W. (2002). Grass defoliation and *Acacia karroo* seedlings: the role of herbaceous competition with encroaching woody plants. (dspace.library.uu.nl/ bitstream/1874/212/4/c3.pdf).

Chirara, C., Frost, P. G. H. and Gwarazimba V. E. E. (2002). Grass defoliation affects survival and growth of seedlings of *Acacia karroo*, an encroaching species in southwestern Zimbabwe. (dspace.library.uu.nl/bitstream/1874/212/15/c2.pdf).

Choge, S. K., Ngunjiri, F. D., Kuria, M. N., Busaka, E. A., Muthondeki, J. K. (2002). The status and impact of *Prosopis spp.* in Kenya. KEFRI, Nairobi.

Cypher, B. L. and Cypher, E. A. (1998). Germination rates of tree seeds ingestedby coyotes and racoons. *American Midland Naturalist,* 142: 71–76.

Coughehenour, M. B. and Detling, J. K. (1986). Acacia tortilis seed germination responses to water potential and nutrients. *African Journal of Ecology,* 24: 203-205. Doi: 10.1111/j.1365-2028.1986.tb00363.x

Dahiye, Y. M. and Aman R. (2002). Population size and seasonal distribution of the hirola antelope (Beatragus hunteri, Sclater 1889) in southern Garissa, Kenya. *African Journal of Ecology,* 40(4):386-389).

Daily Nation Newspaper . Baringo residents' hopes for income fade as Sh 2.2bn 'Mathenge' factory stalls. Retrieved 29 June 2020.

Davis, M.A., Grime, J.P. and Thompson, K. (2000). Fluctuating resources in plant communities: a general theory of invasibility. *Journal of Ecology,* 88: 528–534.

Davis, M. A. and Pelsor, M. (2001). Experimenta support for resource-based mechanistic model of invisibility. *Ecology letters*, 4:421-428.

Daubenmire, R. (1959). A canopy coverage method for vegetation analysis. *Northwest Science,* 33: 43–64.

Distel, R. A., Peláez, D. V., Bóo, R. M., Mayor, M. D. and Elia, O. R. (1996). Growth of *Prosopis caldenia* seedlings in the field as related to grazing history of the site, and in greenhouse as related to different levels of competition from *Stipa tenuis*. *Journal of Arid Environments,* 32:251–257.

Dovie, B. K., Shackleton, C. M. and Witkowski, E. T. F. (2002). Direct-use values of woodland resources consumed and traded in a South African village. *International Journal of Sustainable Development and World Ecology,* 9: 269-283.

Ebrahimi, M., Alireza, M. and Masood, R. (2015). Role of Soil and Topographic features in Distribution of Plant Species (Case study: Sanib Taftan Watershed-Iran). *Ecopersia,* 3(1): 917-932.

Ehrenfeld, J. G. (2003). Effects of Exotic plant invasions on soil Nutrient cycling processes. *Ecosystems*, 6: 503-523.

Ehrenfeld, J. G., Beth, R. and Kenneth, E. (2005). “Feedback in the Plant-Soil System.” *Annual Review of Environment and Resources*, 30: 75-115.

Felker, P., Cannell, G. H., Osborn, J. F., Clark, P. R. and Nash, P. (1983). Effects of irrigation on biomass production of 32 Prosopis (mesquite) accessions. *Experimental Agriculture*, 19: 187-198.

Felker, P. (2003). Management, use and control of Prosopis in Yemen. Mission Report Project number TCP/YEM/0169 (A) August 14, 2003.

Fer, I., Tietjen, B., Jeltsch, F., and Wolff C. (2017). The influence of El Nini-Southern Oscillation regimes on eastern African vegetation and its future implications under the RCP8.5 warming scenario. *Biogeosciences* 14: 4355-4374.

Fernandez-Illescas, C. P. and Rodriguez-Iturbe, I. (2003). Hydrologically driven hierarchical competition-colonization models: the impact of interannual climate fluctuations. *Ecological Monographs*, 73: 207-222.

Foxcroft, L. C. and Richardson, D. M. (2003). Managing alien plant invasions in the Kruger National Park, South Africa. Plant invasions: ecological threats and management solutions (ed. By Child, L. E., Brock, J. H., Brundu, G., Prach, K., Pysek, P., Wade, P. M. and Williamson, M.), pp. 385–404. Backhuys Publishers, Leiden, The Netherlands.

Fourie, F., Mbatha, K., Verster, H. and Van Dyk, G. (2003). The effect of vegetation (Prosopis spp.) on ground water levels in the Rugseer River, Kenhardt, South Africa. WfW Inaugural Research Symposium, August 19-21, 2003

Frost, P. G., Medina, E., Menaut, J. C., Solbrig, O., Swift, M. and Walker, B. H. (eds). (1986). Response of savannas to stress and disturbance. Biology International Special Issue 10, IUBS, Paris.

Gachathi, F. N., Johansson S. and Alakoski-Johansson G. (1987). A Check List Hughes, F. M. R. (1988). The ecology of African floodplain forests in semi-arid and arid zones: a review. *Journal of Biogeography,* 15: 127-140.

Getachew, S., Sebsebe D. and Tadesse W. (2012). Allelopathic effects of invasive *Prosopis juliflora* (sw.) DC. On selected native plants in middle Awash, Southern Afar Rift of Ethiopia. *Management of Biological Invasions*, 3(2): 105-114.

Gholinejad, B., Asghar, F. and Hossein, P. (2012). Environmental factors affecting on distribution of plant communities in semi-arid area (Case study: Kamyaran rangelands, Iran). *Anals of Biological Research,* 3(8): 3990-3993.

Graham, C. H., Smith, T. B. and Languy, M. (2005). Current and historical factors influencing patterns of species richness and turnover of birds in the Gulf of Guinea Highlands. *Journal of Biogeography,* 32: 1371-1384.

Goldberg, D. (1990). Components of resource competition in plant communities. In: Grace, J. B. and Tilman, D. (eds), Perspectives on Plant Competition, pp 51-55. Academic Press, New York.

Gomez-Aparicio, L., Gomez, J. M., Zamora, R. and Boettinger, J. L. (2005). Canopy vs soil effects of shrubs facilitating tree seedlings in Mediterranean Montane ecosystems. *Journal of Vegetation Science*, 16: 191-198.

Gooden, B. and French, K. (2014). Non-interactive effects of plant invasion and landscape modification on native communities. Diversity and Distributions: *Journal of Conservation Biogeography*, 20 (6): 626-639.

Grellier S., Barot S., Janeau J. and Ward D. (2012). Grass competition is more important than seed ingestion by livestock for Acacia recruitment in South Africa. *Plant Ecology*, 213:899-908.

Hagos, M., Samucisson, G., Kenne, L. and Modawi, B.M. (1987). Isolation of smooth muscle relaxing 1, 3-diaryl-propan-2-ol derivatives from *Acacia tortilis*. *Planta Medica*, 53:27-31.

Hazelton, P. A. and Murphy, B. W. (2007) Interpreting Soil Test Results: What Do All The Numbers Mean?. CSIRO Publishing: Melbourne.

Hejda, M., Pysek, P. and Vojtéch, J. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology*, 97: 393-403.

Henderson, L. (2007). Invasive, naturalized and casual alien plants in southern Africa: a summary based on the Southern African Plant Invaders Atlas (SAPIA). *Bothalia*, 37:215-248.

Higgins, S. I., Bond, W. J. and Trollope, W. S. W. (2000). Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecology*, 88: 213-229.

House, J., Archer, S., Breshears, D. D., Scholes, R. J. and NCEAS Tree-Grass Interaction Participants. (2003). Conundrums in mixed woody-herbaceous plant systems. *Journal of Biogeography*, 30: 1763-1777.

Howell, J. and Benson, D. (2000). Predicting potential impacts of environmental flows on weedy riparian vegetation of Hawkesbury-Nepean River, South-eastern Australia. *Austral Ecology*, 25:463-475.

Hughes, F. M. R. (1988). The ecology of African floodplain forests in semi-arid and arid zones: a review. *Journal of Biogeography*, 15: 127–140.

Hughes, F. M. R. (1990). The influence of flooding regimes on forest distribution and composition in the Tana River Floodplain, Kenya. *The Journal of Applied Ecology*, 27: 475-491.

Intergovernmental Panel on Climate Change (2007). ‘Climate Change and Human Development in Africa: Assessing the Risks and Vulnerability of Climate Change in Kenya, Malawi and Ethiopia’, (Nairobi:UNDP).

IUCN (1996). IUCN Red List of Threatened Animals. IUCN. Grand, Switzerland

IUCN (2003). Tana River, Kenya: integrating downstream values into hydropower planning. Case studies in wetland valuation No. 6.

Iwara, A. I., Gani, B. S., Njar, G. N. and Deekor, T. N. (2011).Influence of Soil Physico-chemical Properties on the Distribution of woody Tree/Shrub Species in South-Southern Nigeria. *Journal of Agriculrural Science*, 2(2): 69-75.

Jeltsch, F., Weber, G. E. and Grimm, V. (2000). Ecological buffering mechanisms in savannas: a unifying theory of long-term tree-grass coexistence. *Plant Ecology*, 150:161-171.

Kahi, C. H., Ngugi, R.K., Mureithi, S.M. and Ng'ethe, J.C. (2009). The canopy effects of *Prosopis juliflora* (DC.) and *Acacia tortilis* (HAYNE) trees on herbaceous plants species and soil Physico-chemical properties in Njemps Flats, Kenya. *Tropical and Subtropical Agroecosystems*, 10:441- 449.

Kalema, V. N. and Witkowski, E. T. F. (2012). Land-use impacts on woody plant density and diversity in an African savanna charcoal production region. *International Journal of Biodiversity Science, Ecosystem Services and Management,* 8 (3): 231-247.

Kamau, P. (2004). Forage Diversity and Impact of Grazing Management on Rangeland Ecosystems in Mbeere District, Kenya. Land Use Change Impacts and Dynamics (LUCID) Project Working Paper Number 36. Nairobi, Kenya: International Livestock Research Institute.

KWS (1996). Land use survey and census of communities directly dependent on Tana River Primate National Reserve. Report to World Bank for the Tana GEF project.

Kohyama, T. (1993). Size-structured tree populations in gap-dynamic forest- The forest architecture hypothesis for the stable coexistence of species. *Journal of Ecology,* 81 (1): 131-143.

Kolb, A., Alpert, P., Enters, D. and Holzapfel, C. (2002). Patterns of invasion within a grassland community. *Journal of Ecology*, 90:871-881.

Kramer, P. J. (1980). Drought stress and the origin of adaptations. In: Adaptations to Water and High Temperature Stress (Eds N. C. Turner and P.J. Kramer). John Wiley & Sons, New York.

Kristensen, M. and Lykke, A. M. (2003). Informant-Based Valuation of use and Conservation Preferences of Savanna Trees in Burkina Faso. *Economic Botany*, 57(2): 203-217.

Kulmatiski, A., Karen, H. B, John R. S. and Stephanie, M. C. (2008). "Plant–soil Feedbacks: a Meta-analytical Review." *Ecology Letters*, 11: 980-992.

Le Houerou, H. N. (1980). Chemical Composition and nutritional value of browse in tropical West Africa. In H.N. Houerou (ed.), Browse in Africa, the current state of knowledge. ILCA, Ethiopia pp 261-289.

Levine, J. M., Vila, C. M., D’ Antonio, J. S. Dukes, K. G. and Lavorel, S. (2003). Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London. *Series B-Biological Sciences* 270:777-781.

Loth, P. E., De Boer, W. F., Ignas, M. A. H. and Herbert, H. T. P. (2005). Germination strategy of the E. African Savanna tree *Acacia tortilis. Journal of Tropical Ecology*, 21:509-517.

Lovejoy, T. E. and Hannah, L. (eds). (2006). Climate change and biodiversity. Yale University Press.

Low, T. (2008). Climate Change and Invasive Species, A Review of interactions- November 2006 Workshop Report by the Biological Diversity Advisory Comittee (BDAC), Commonwealth of Australia.

Lynch, M. and Lande, R. (1993). Evolution and extinction in response to environmental change Pp. 234-250 in P.M. Kareiva, J. G. Kingsolver and R. B. Huey, (eds.), Biotic interactions and global change, sinauer, Sunderland MA. *International journal of climatology,* 14:827-828.

Mackey, B. (2007). “Climate change, connectivity and biodiversity conservation”. In Taylor M., Figgis P. Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, Canberra, 18-19 June 2007”. Sydney: WWF- Australia, pp. 90-6

McKenzie, N. J., Jacquier, D. J., Isbell, R. F. and Brown, K. L. (2004). Australian Soils and Landscapes: An Illustrated Compendium. http://www.publish.csiro.au/pid/3821.htm

Mahmood, K., Chughtai, M. I., Awan, A. R. and Waheed, R. A. (2016). Biomass production of some salt tolerant tree species grown in different ecological zones of Pakistan. *Pakistan Journal of Botany,* 48: 89-96.

Maingi, J. K. and Marsh, S.E. (2002). Quantifying hydrologic impacts following dam construction along the Tana River, Kenya. *Journal of Arid Environments*, 50: 53–79.

Maingi, J. K. (2006). Growth Rings in Tree Species from the Tana River floodplain, Kenya. *Journal of East African Natural History,* 95: 181-211.

Marcia, A. R. and Anderson, R. C. (2004). Effects of nitrogen addition on the invasive grass *Phragmites australis* and a native competitor *Spartina pectinata*. *Journal of Applied Ecology* 41: 888-896.

Maundu, P., Kibet, S., Morimoto, Y., Imbuni, M. and Adeka, R. (2009). Impact of *Prosopis juliflora* on Kenya’s semi-arid and arid ecosystems and local livelihoods. *Biodiversity,* 10:33-50.

Mligo, C., Lyaruu, H. V. M., Ndangalasi, H. J. and Marchant, R. (2009). Vegetation community structure, composition and distribution pattern in the Zaraninge Forest, Bagamoyo District, Tanzania. *Journal of East African Natural History,* 98, 223-239.

Mligo, C. (2016). Plant species response to variation in soil nutrient saturation gradients in Zaraninge Forest, Tanzania. *African journal of Ecology*, 55:134-144.

Mogaka, H., Davis, R., Gichere, S. And Hirji, R. (2006). Climate variability and water resources degradation in Kenya: Improving water resources development and management. World Bank Working Paper. 1-105.

Munishi, P. K. T., Shear, T. H., Wentworth, T. and Temu, R. A. P. C. (2007). Compositional gradients of plant communities in submontane rainforests of Eastern Tanzania. *Journal of Tropical Forest Science*, 19(1): 35-45.

Muoria, P. K., Karere, G. M., Moinde, N. N. and Suleman M. A. (2003). Primate census and habitat evaluation in Tana delta region, Kenya. *African Journal of Ecology*, 41: 157-163.

Muturi, G. M., Mohren, G. M. J. and Kimani, J. N. (2009). Prediction of *Prosopis* species invasion in Kenya using geographical information system techniques. *African Journal of Ecology*, 48: 628-636.

Mwangi, E. and Swallow, B. (2005). Invasion of *Prosopis juliflora* and local livelihoods: A case study from the lake Baringo area, Kenya. Agroforestry Center, Nairobi.

Mworia, J. K., Kinyamario, J. I. and John, E. A. (2009). Impact of the invader Ipomoea hildebrandtii on grass biomass, nitrogen mineralisation and determinants of its seedling establishment in Kajiado, Kenya. *African Journal of Range & Forage Science,* 25(1): 11-16.

Mworia, J. K., Kinyamario, J. I., Omari, J. K. and Wambua, J. K. (2011). Patterns of seed dispersal and establishment of the invader *Prosopis juliflora* in the upper floodplain of Tana River, Kenya. *African Journal of Range and Forage Science*, 28: 35-41.

Nelson and Sommers (1975) in Okalebo, J. R., Gathua, K. W., Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual; 2nd Edition. Sacred African Publishers, Nairobi, Kenya.

Oba, G., Stenseth, N. C. and Weldaji, R. B. (2002). Impacts of shifting agriculture on a floodplain woodland regeneration in dryland, Kenya. Agriculture, *Ecosystems & Environment*, 90:211-216.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual; 2nd Edition. Sacred African Publishers, Nairobi, Kenya.

Olukoye, G. A., Wamicha, W. N. and Kinyamario, J. I. (2003) Assessment of the performance of exotic and indigenous tree and shrub species for rehabilitating saline soils of Northern Kenya. *African Journal of Ecology*, 41: 164–170.

Omari, J. K., J. K. Mworia, N. Gichuki and C. Mligo (2019). Woody Species Composition in Upper Tana River Floodplain of Kenya: Potential Effects of Change in Flood Regimes. *Journal of Sustainability, Environment and Peace*, 1 (3) 91-97.

Otiende, B. (2009). The Economic Impacts of Climate Change in Kenya: Riparian Flood Impacts and Cost of Adaptation. http://kenya.cceconomics.org/kedo/kenya-riparian-floods-case study.

Ortega, Y. K. and Pearson, D. E. (2005). Weak Vs strong invaders of natural plant communities: Assessing invisibility and impact. *Ecological Applications*, 15:651-661.

Otieno, D. O., Kinyamario, J. I. and Omenda, T. O. (2001). Growth features of Acacia tortilis and Acacia xanthophloea seedlings and their response to cyclic soil drought stress. East African Wild Life Society, *African Journal of Ecology*, 39: 126-132.

Owens, C. S., William, J. F., Skogerboe, J. G. and Smirt, R. M. (2007). Distribution and abundance of Eurasian watermilfoil (*Myriophyllum spicatum* L.) and Curly-leaf pondweed (*Potamogeton crispus* L.) in Shiwano Lake, Wisconsin. Wiley Interscience Ecology ADA472524.

Padiel, A. A., Carvalho, P., Thomaz, S.M., Boschilia, S.M., Rodrigues, R.B. and Kobayashi, J.T. (2009). The role of an extreme flood disturbance on macrophyte assemblages in a Neotropical flooplain. *Aquatic Sciences*, 71:389-398.

Pasiecznik, N. M. (1999). *Prosopis*—pest or providence, weed or wonder tree? *European Tropical Forest Research Network Newsletter*, 28:12-14.

Pasiecznik, N. M., Felker, P. and Harris, P. J. C. (2001). The *Prosopis juliflora-Prosopis pallida* complex: A Monograph. HDRA, Coventry, UK.

Payne, R.W., Murray, D.A., Harding, S.A., Baird, D.B. and Soutar, D.M. (2012) Genstat® for Windows™. 15th Edition, Introduction, VSN International, Oxford

Peinnetti, R., Pereyra, M., Kin, A. and Sosa, A. (1993). Effects of cattle ingestion on viability and germination rate of calden *(Prosopis caldenia)* seeds. *Journal of Range Management*, 46: 483-486.

Peláez, D. V., Bóo, R. M. and Elia, O. R. (1992). Emergence and seedling survival of caldén in the semiarid region of Argentina. *Journal of Range Management*, 45: 564-568.

Peltzer, D. A. and Kochy, M. (2001). Competitive effects of grasses and woody plants in mixed - grass prairie. *Journal of Ecology*, 89:519-527.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E. and Stromberg, J.C. (1997). The natural flow regime: a paradigm for river conservation and restoration. *Bioscience*, 47:769-784.

Polley, H. W., Johnson, H. B. and Tischler, C. R. (2002). Woody invasions of grasslands: evidence that CO2 enrichment indirectly promotes establishment of Prosopis glandulosa. *Plant Ecology*, 164: 85-94.

Pulido, M., Schnabel, S., Lavado-Contador, J. F., Lozano-Parra, J. *and* González, F. *(*2016*)* The Impact of Heavy Grazing on Soil Quality and Pasture Production in Rangelands of SW Spain. Land Degrad. Develop.*, doi:* 10.1002/ldr.2501.

Raghubanshi, A. S., Rai, L. C., Gaur, J. P. and Singh J. S. (2005): Invasive alien species and Biodiversity in India: *Current Science,* 88 (4): 539-540.

Reid, R.S. and J.E. Ellis. 1995. Livestock-mediated tree regeneration: impacts of pastoralists on dry tropical woodlands. *Ecological Applications*, 5:978-992.

RoK (2007), 'National Policy on Disaster Management,' (Nairobi: Ministry of Special Programmes).

Resh, V. H., Brown, A.V., Corich, A. P., Li, H.W., Minshall, W., Reice, S. R., Sheldon, A. L., Wallace, J. B. and Wissmar, R.C. (1988). The role of disturbance in stream ecology. *Journal of North American Benthological Society,* 7:433-455.

Rice, K. J. and Emery, N. C. (2003). Managing microevolution: Restoration in the face of global change. *Frontiers in Ecology and Environment*, 9:469-478.

Riginos, C. (2009). Grass competition suppresses savanna tree growth across multiple demographic stages. *Ecology,* 90:335-340

Robert, J., James, W. D., Kyle E. H., Joseph, B. Y., Robert F. S., Mathew, M. (2006). Proceedings of the National Academy of Sciences www.pnas.org. *Current Issue,* 104 (3): 864-869; doi: 10.1073/pnas.0604666104.

Rohner, C. and Ward, D. (1999). Large Mammalian Herbivores and Conservation of arid Acacia stands in the Middle East. *Conservation Biology,* 13: 1162-1171.

Sahney, S., Benton, M. J. and Falcon-lang, H. J. (2010). " Rainforest collapse triggered Pennsylvanian tetrapod diversification in Euramerica. *Geology,* 38 (12): 1079-1082. doi: 10.1130/G 31182.1

Sala, O. E., Golluscio, R. A., Laurenroth, W. K. and Soriano, A. (1989). Resource partitioning between shrubs and grasses in the Patagonian steppe. *Oecologia, 81*: 501-505.

Sankaran, M. R., J. and Hanan, N. P. (2004). Tree grass coexistence in savannas revisited-insights from an examination of assumptions and mechanisms invoked in existing models. *Ecology Letters,* **7**: 480-490.

Saraswathi, K. and Chandrasekaran, S. (2016). Biomass yielding potential of naturally regenerated *Prosopis juliflora* tree stands at three varied ecosystems in Southern districts of Tamil Nadu, India. *Environmental Science and Pollution Research,* 23: 9440-9447.

Scholes, R. J. (1990). The influence of soil fertility on the ecology of southern African dry savannas. *Journal of Biogeography,* 17:425-429.

Scholes, R. J. and Archer, S. R. (1997). Tree-grass interactions in savannas. *Annual Review of Ecology and Systematics*, 28: 517-544.

Schwinning, S. and Ehleringer, J. R. (2001). Water use trade-offs and optimal adaptatiom to pulse-driven arid ecosystems. *Journal of Ecology,* 89: 464–480.

Shiferaw, H., Teketay, D., Nemomissa, S. and Assefa, F. (2004) Some biological characteristics that foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, northeastern Ethiopia. *Journal of Arid Environments*, 58: 134–153.

Singh, V. P., Dixit, A., Mishra, J. S. and Yaduraju, N. T. (2004). Effect of period of soil solarisation and weed-control measures on weed growth, and productivity of soybean (Glycine max). *Indian Journal of Agricultural Sciences*, 74: 324-328.

Skarpe, C. (1990). Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. *Journal of Applied Ecology, 27*: 873-885.

Smith, T. M. and Shackleton S. E. (1988). The effects of shading on the establishment and growth of *Acacia tortilis* seedlings. *South African Journal of Botany*, 54:375-379.

Smith, T. M. and Goodman, P. S. (1986). The effect of competition on the structure and dynamics of Acacia savannas in southern Africa. *Journal of Ecology*, 74: 1031-1044.

Speranza, C. I., Kiteme, B. and Wiesmann, U. (2008). Droughts and famines: the underlying factors and the causal links among agro-pastoral households in semi-arid Makueni district, Kenya. *Global Environmental Change in Human and Policy Dimensions*, 18: 220-233.

Stave, J., Oba, G., Nordal, I. and Stenseth, N. C. (2006) Seedling establishment of *Acacia tortilis* and *Hyphaene compressa* in the Turkwel riverine forest, Kenya. *African Journal of Ecology*, 44: 178-185.

Stevens, P. A. and Hornung, M. (1990). Effect of harvest intensity and ground flora establishment on inorganic-N leaching from a Sitka spruce plantation in north Wales. *Biogeochemistry*, 10: 53–65.

Suleman, M. A., Wahungu, G. M., Muoria, P. K., Karere, G. M., Oguge, N. and Moinde, N. N. (2001). Tana River primate census and forest evaluation. A report to Kenya Wildlife Services.

Tate, K. W., Dudley, D. M., Mcdougald, N. K. and Melvin, R. G. (2004). Effect of canopy and grazing on soil bulk density. *Journal of Range Management*, 57 (4): 411-417.

Ter Braak, C. and Šmilauer, P. (2012). Canoco Reference Manual and User's Guide: Software for Ordination (version 5.0). Microcomputer power, Itaca, www. canoco. Com, pp 496.

Tilman, D. (1997). Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology,* 78: 81-92.

Tjelele, T. J., Dziba, L. E. and Pule, H. T. (2012). Recovery and germination of Dichroatachys cinerea seeds fed to goats (Capra hircus). *Rangeland Ecology and Management*, 65:105-108.

Trammell, T. L. E. and Carreiro, M. M. (2011). Vegetation composition and structure of woody plant communities along urban interstate corridors in Louisville, KY, USA. *Urban Ecosystems*, 14: 501-524.

Udoh, B. T., Ogunkunle, A. O. and Ndaeyo, N. U. (2007). Influence of soil series and physic-chemical properties on weed flora distribution at Moor Plantation Ibadan Southwestern Nigeria. *Journal of Agriculture and Social Sciences*, 3 (2): 55-58.

UNEP (2000). Devastating Droughts in Kenya: Environmental Impacts and Responses. UNEP, Nairobi, Kenya.

Van-Auken, O. W. (2000). Characteristics of intercanopy bare patches in Juniperus woodlands of the southern Edwards Plateau. *Texas Southwestern Naturalist*, 45: 95-110.

Van den Berg, L. and Kellner, K. (2005). Restoring degraded patches in a semi-arid rangeland of South Africa. *Journal of Arid Environments*, 61: 497-511.

Van Langevelde, F., Van de Vijver, C. A. D. M., Kumar, L. Van de Koppel, J., De Ridder, N., Van Andel, J. *et al.* (2003). Effects of fire and herbivory on the stability of savanna ecosystems. *Ecology,* 84: 337-350.

Van Wijk, M. T. and Rodriguez-Iturbe., I. (2002). Tree-grass competition in space and time: insights from a simple cellular automata model based on ecohydrological dynamics. *Water Resources Research*, 38: 18.11-18.15.

Walker, B. H. and Noy-Meir, I. (1982). Aspects of stability and resilience of savanna ecosystems. In: Ecology of tropical savannas (eds. Walker, B. J. & Huntley, B. H). Springer-Verlag, Berlin, pp 556-590.

Walker, B. H., Ludwig, D., Holling, C. S. and Peterman R. S. (1981). Stability of semi-arid savanna grazing systems. *Journal of Ecology*, 69: 473-498.

Walter H. (1971). Ecology of Tropical and sub-tropical Vegetation. Oliver and Boyd, Edinburgh, UK (1971).

Ward, J. V., Tockner K., Arscott D. B. and Claret C. (2006). Beaver dams and overbank floods influence ground water-surface water interactions of a Rocky Mountain riparian area. In Bayley S. E. and Guimond J. K. (2008). Effects of river connectivity on marsh vegetation community structure and species richness in montane floodplain wetlands in Jasper National Park, Alberta, Canada. *Ecoscience*, 15:377-388.

Weitbrecht, K.(1), Müller, K., Leubner-Metzger, G. (2011). First off the mark: early seed germination. *Journal of Experimental Botany*, 62(10): 3289-3309. Doi: 10.1093/jxb/err 030

Winkler, M., Kal, H. and Peter, H. (2005). Effect of canopy position on Germination and seedling survival of Epiphytic Bromeliads in Mexican Humid Montane forest. *Annals of Botany*, 95:1039-1047.

Zar, H. J. (1999). Biostatistical Analysis. Prentice Hall Inc. Englewood Cliffs, New Jersey.

Zare, S., Jafari, M., Tavili, A., Abbasi, H. and Rostampour, M. (2011). Relationship between environmental factors and plant distribution in arid and semi-arid areas (case study: Shahriyar Rangelands, Iran). *American-Eurasian Journal of Agriculture and Environmental Science*, 10 (1): 97-105.

Zhou, Z. C., Gan, Z. T., Shangguan Z. P. and Dong, Z. B. (2010). Effects of grazing on soil physical properties and soil erodibility in semi-arid grassland of the Northern Loess Plateau (China). *Catena*, 82: 87-91.

APPENDICES

Appendix 1: Tree species in the study area, authors and families

Tree species	Family
Acacia elatior Brenan	Fabaceae
Acacia nilotica L.	Fabaceae
Acacia robusta Burch.	Fabaceae
Acacia tortilis (Forssk.) Hayne	Fabaceae
Acacia zanzibarica (S. Moore) Taub.	Fabaceae
Alangium salviifolium (L.f)	Cornaceae
Albizia anthelmintica Brongn.	Fabaceae
Azadirachta indica A.Juss	Meliaceae
Balanites pedicellaris (Welw.) Mildbr. & Schltr	Zygophyllaceae
Blighia unijugata Bak.	Sapindaceae
Boscia coriacea Pax	Capparaceae
Celtis philippensis Blanco	Cannabaceae
Commiphora africana (A.Rich.)	Burseraceae
Commiphora baluensis Engl.	Burseraceae
Commiphora campestris Engl.	Burseraceae
Commiphora riparia Engl.	Burseraceae
Commiphora schimperi (O.Berg) Engl.	Burseraceae
Cordia goetzei Gürke	Boraginaceae
Diospyros abyssinica (Hiern) F.White	Ebenaceae
Dobera glabra (Forssk.) Poir.	Salvadoraceae
Dobera loranthifolia Warb. Harms	Salvadoraceae
Drypetes natalensis (Harv.) Hutch.	Euphorbiaceae
Eucalyptus saligna Sm.	Myrtaceae
Excoecaria madagascariensis (Baill.) Müll. Arg	Euphorbiaceae
Ficus sycomorus L.	Moraceae
Grewia bicolor Juss.	Tiliaceae
Hunteria zeylanica (Retz.) Gardner	Apocynaceae
Hyphaene compressa H.Wendl.	Arecaceae
Kigelia africana (Lam.) Benth.	Bignoniaceae
Lannea schweinfurthii (Engl.) Engl. var. stuhlmannii (Engl.) Kokwaro	Anarcadiaceae
Lecaniodiscus fraxinifolius Baker	Sapindaceae
Maerua pubescens Klotzsch Gilg	Capparaceae
Mangifera indica L.	Anarcardiaceae
Musa paradisiaca L.	Musaceae
Pavetta sphaerobotrys subsp. tanaica (Bremek.) Bridson	Rubiaceae
Phoenix reclinata Jacq.	Arecaceae
Polysphaeria multiflora Hiern	Rubiaceae

Prosopis juliflora (Sw.) DC.	Fabaceae
Rinorea elliptica (Oliv.) Kuntze	Violaceae
Salvadora persica L.	Salvadoraceae
Sorindeia madagascariensis DC.	Anacardiaceae
Sterculia africana (Lour.) Fiori	Sterculiaceae
Tamarindus indica L	Fabaceae
Tapura fischeri Engl.	Dichapetalaceae
Terminalia brownii Fres	Combretaceae
Terminalia parvula Pampan	Combretaceae
Terminalia spinosa Engl.	Combretaceae
Ziziphus pubescens Oliv.	Rhamnaceae

Appendix 2a: Soil characteristics inside the floodplain

Trans.	Bd	Mois	pH	C	N	P	K	Mg	Ca	CEC
Tc	1.04	12.80	6.78	1.24	0.09	148.5	585.5	465.1	1857.5	8.8
Tc	1.36	13.06	6.75	0.69	0.07	189.9	447.7	521.5	1486.0	7.8
Tc	1.18	12.15	7.53	2.59	0.24	82.4	1067.6	865.6	3436.4	17.2
Tc	1.19	14.96	7.28	1.07	0.12	151.6	482.1	427.4	1393.1	7.2
Tc	1.42	7.26	7.3	0.53	0.07	139.0	344.4	298.4	928.8	5.2
BEg	1.27	12.77	7.75	1.09	0.12	167.8	1170.9	1145.2	3715.1	18.0
BEg	1.40	13.47	7.24	1.10	0.14	159.4	1205.4	1029.6	3529.3	17.3
BEg	1.32	13.39	7.07	0.15	0.04	169.5	654.3	532.3	2043.3	9.8
Ac	1.33	16.53	7.54	2.19	0.21	158.3	1274.2	1094.1	3529.3	17.9
Ac	1.29	13.51	7.46	1.07	0.09	148.8	861.0	862.9	2414.8	12.7
Ac	1.37	13.57	7.88	0.79	0.09	173.4	861.0	733.9	2414.8	12.2
Bg	1.25	16.04	7.81	0.75	0.09	167.8	1446.4	1158.6	3900.8	19.0
Ba	1.08	15.92	8.02	1.32	0.11	313.6	1446.4	814.5	3900.8	17.9
Bg	1.38	4.75	8.17	2.00	0.1	142.1	1205.4	871.0	3250.7	15.7
Bg	1.17	12.18	6.6	0.15	0.17	185.5	792.1	553.8	2229.0	10.8
Ma	1.16	18.57	7.87	0.56	0.05	219.9	826.5	505.4	2321.9	10.2
Ma	1.42	7.26	7.75	0.16	0.08	167.8	482.1	293.0	1207.4	6.1
Ma	1.39	5.74	8.02	1.63	0.04	177.3	619.9	510.8	1857.5	9.4
Ma	1.50	7.72	7.55	1.32	0.14	146.0	861.0	446.2	2507.7	11.2
Ha	1.25	11.29	7.79	0.14	0.12	165.6	757.7	569.9	2136.2	10.6
Ha	1.33	10.70	8.16	0.29	0.04	196.1	964.3	639.8	2693.4	12.4
Ha	1.34	9.83	8.07	0.95	0.05	165.0	929.8	637.1	2507.7	12.3
Ha	1.50	8.04	8.0	0.51	0.04	211.2	792.1	349.5	2043.3	9.4
Wa	1.40	9.04	8.33	0.62	0.04	148.8	447.7	483.9	1578.9	7.2
Wa	1.26	7.48	8.05	0.54	0.06	174.5	585.5	387.1	1578.9	7.7
Wa	1.11	7.84	7.69	0.99	0.1	212.3	964.3	817.2	2786.3	13.9
Wg	1.16	14.23	7.34	2.75	0.16	174.0	1239.8	951.6	3436.4	16.7
Ca	1.18	22.95	7.72	1.20	0.08	182.9	1343.1	1188.2	3900.8	18.8
Ca	1.17	18.73	7.44	1.52	0.11	231.6	1480.9	1010.8	3993.7	19.0
Ca	1.12	22.03	7.25	1.62	0.1	160.0	1377.6	1172.0	3622.2	17.7

KEY:
Trans.-Transect; Bd-Bulk density; Mois-Moisture; CEC-Cation Exchange Capacity
Land uses
c- Wildlife conservation; g-Livestock grazing; a-Irrigated agriculture
Areas (Sites)
T- Tana River National Reserve; H- Hola; BE- Bura East; W- Wenje; A-Arawale National Reserve; C- Chanani; BI-Bura Irrigation Scheme; M- Makere; HI- Hola Irrigation Scheme; B-Bura

Appendix 2b: Soil characteristics outside the floodplain

Trans.	Bd	Mois	pH	C	N	P	K	Mg	Ca	CEC
Tc	1.61	4.23	6.28	0.53	0.07	73.7	241.1	537.6	743.0	5.6
Tc	1.64	4.51	6.59	1.11	0.11	65.0	619.9	677.4	1950.4	10.4
Tc	1.50	14.90	6.16	0.69	0.1	83.9	688.8	975.8	2136.2	11.2
Tc	1.58	8.88	5.93	1.48	0.13	58.2	206.6	287.6	650.1	3.9
Tc	1.60	6.98	5.82	0.42	0.06	63.8	137.8	231.2	371.5	2.8
Tc	1.51	11.83	7.3	1.22	0.13	98.6	344.4	317.2	1021.6	5.5
BEg	1.87	3.75	9.17	0.29	0.05	111.7	275.5	301.1	743.0	7.4
BEg	1.72	5.25	8.39	0.10	0.04	40.0	413.3	502.7	1300.3	10.3
BEg	1.51	6.28	8.59	0.48	0.06	129.7	447.7	368.3	1300.3	6.7
Ac	1.82	3.50	7.97	1.24	0.08	69.1	1859.7	572.6	4829.6	28.6
Ac	1.86	2.52	7.89	0.95	0.1	38.5	1894.1	766.1	5015.3	23.9
Ac	1.85	4.45	8.36	1.49	0.15	95.7	1790.8	526.9	4643.8	19.0
Ac	1.57	7.34	7.68	0.69	0.08	21.7	619.9	639.8	1671.8	9.4
BIa	1.73	1.34	7.72	0.56	0.08	87.1	2204.1	1201.6	5386.8	24.2
BIa	1.41	7.20	7.71	0.42	0.07	38.0	723.2	491.9	1857.5	9.2
Bg	1.67	2.94	6.79	0.15	0.04	100.6	172.2	161.3	464.4	2.9
Bg	1.44	5.58	7.65	0.96	0.07	266.3	1033.2	629.0	2786.3	13.1
Mg	1.40	3.53	8.2	0.29	0.06	69.0	413.3	333.3	1021.6	5.7
Mg	1.67	2.14	4.26	0.67	0.09	138.5	929.8	518.8	2414.8	10.7
Mg	1.56	4.08	7.8	1.64	0.15	278.6	1412.0	559.1	3715.1	16.3
Mg	1.43	6.97	7.72	0.81	0.11	120.3	378.8	274.2	1021.6	5.2
HIa	1.51	3.12	5.43	0.10	0.05	113.8	688.8	462.4	1857.5	9.2
HIa	1.58	12.19	6.13	0.69	0.09	103.5	241.1	212.4	650.1	3.7
Wg	1.48	1.07	7.37	1.50	0.08	70.5	1274.2	645.2	3529.3	14.8
Wg	1.65	9.84	7.23	1.62	0.11	174.8	1033.2	602.2	2972.0	13.5
Wg	1.60	10.36	6.67	1.87	0.14	117.5	241.1	247.3	650.1	3.8
Wg	1.26	10.57	8.44	0.87	0.13	69.0	68.9	115.6	185.8	1.6
Cg	1.38	9.46	7.4	1.25	0.05	142.7	551.0	884.4	2600.5	12.3
Cg	1.61	8.23	7.13	1.10	0.09	117.1	344.4	314.5	743.0	4.7
Cg	1.68	2.34	6.41	0.96	0.09	88.4	275.5	306.5	650.1	4.2

KEY:
Trans.-Transect; Bd-Bulk density; Mois-Moisture; CEC-Cation Exchange Capacity
Land uses
c- Wildlife conservation; g-Livestock grazing; a-Irrigated agriculture
Areas (Sites)
T- Tana River National Reserve; BE- Bura East; W- Wenje; A-Arawale National Reserve; C-Chanani; BI-Bura Irrigation Scheme; M- Makere; HI- Hola Irrigation Scheme; BI – Bura Irrigation Scheme; B-Bura

Appendix 3a: Soil characteristics in wildlife conservation areas

Trans.	Bd	Mois	pH	C	N	P	K	Mg	Ca	CEC
Ti1	1.04	12.80	6.78	1.24	0.09	148.5	585.5	465.1	1857.5	8.9
Ti2	1.36	13.06	6.75	0.69	0.07	189.9	447.7	521.5	1486.0	7.8
To3	1.18	12.15	7.53	2.59	0.24	73.7	241.1	537.6	743.0	5.6
To4	1.19	14.96	7.28	1.07	0.12	65.0	619.9	677.4	1950.4	10.4
Ti5	1.42	7.26	7.3	0.53	0.07	82.4	1067.6	865.6	3436.4	17.2
To7	1.27	12.77	7.75	2.19	0.21	83.9	688.8	975.8	2136.2	11.2
To8	1.40	13.47	7.24	1.07	0.09	58.2	206.6	287.6	650.1	3.9
To9	1.32	13.39	7.07	0.79	0.09	63.8	137.8	231.2	371.5	2.8
To10	1.61	4.23	6.28	0.53	0.07	98.6	344.4	317.2	1021.6	5.5
Ti11	1.64	4.51	6.59	1.11	0.11	151.6	482.1	427.4	1393.2	7.2
Ti12	1.50	14.90	6.16	0.69	0.10	139.0	344.4	298.4	928.8	5.2
To19	1.58	8.88	5.93	1.48	0.13	69.1	1859.7	572.6	4829.6	28.7
To20	1.60	6.98	5.82	0.42	0.06	38.5	1894.1	766.1	5015.3	23.9
To21	1.51	11.83	7.3	1.22	0.13	95.7	1790.8	526.9	4643.8	19.0
To22	1.86	3.75	9.17	1.24	0.08	21.7	619.9	639.8	1671.8	9.4
Ti23	1.72	5.25	8.39	0.95	0.10	158.3	1274.2	1094.1	3529.3	17.9
Ti24	1.51	6.28	8.59	1.49	0.15	148.8	861.0	862.9	2414.8	12.8
Ti25	1.82	3.50	7.97	0.69	0.08	173.4	861.0	733.9	2414.8	12.2

KEY:
Ti - Transect inside the floodplain
To- Transect outside the floodplain

Trans. - Transect
Bd - Bulk density
Mois - Moisture
CEC - Cation Exchange Capacity

Appendix 3b: Soil characteristics in livestock grazing areas

Trans.	Bd	Mois	pH	C	N	P	K	Mg	Ca	CEC
Ti13	1.33	16.53	7.54	1.09	0.12	167.8	1170.9	1145.2	3715.1	18.0
Ti14	1.29	13.51	7.46	1.10	0.14	159.4	1205.4	1029.6	3529.3	17.3
Ti15	1.37	13.57	7.88	0.15	0.04	169.5	654.3	532.3	2043.3	9.8
To16	1.25	16.04	7.81	0.75	0.11	111.7	275.5	301.1	743.0	7.4
To17	1.08	15.92	8.02	2.00	0.17	40.0	413.3	502.7	1300.3	10.3
To18	1.38	7.26	8.17	0.15	0.05	129.7	447.7	368.3	1300.3	6.7
To29	1.17	12.18	6.6	2.75	0.16	100.6	172.2	161.3	464.4	2.9
To30	1.87	2.52	7.89	0.29	0.05	266.3	1033.2	629.0	2786.3	13.1
Ti31	1.85	4.45	8.36	0.10	0.04	167.8	1446.4	1158.6	3900.8	19.0
Ti33	1.57	7.34	7.68	0.48	0.06	142.1	1205.4	871.0	3250.7	15.7
Ti34	1.73	7.20	7.72	0.15	0.04	185.5	792.1	553.8	2229.0	10.8
To35	1.41	1.34	7.71	0.96	0.07	69.0	413.3	333.3	1021.6	5.7
To38	1.67	2.94	6.79	0.29	0.06	138.5	929.8	518.8	2414.8	10.7
To39	1.44	5.58	7.65	0.67	0.09	278.6	1412.0	559.1	3715.1	16.3
To40	1.40	3.53	8.2	1.64	0.15	120.3	378.8	274.2	1021.6	5.2
Ti53	1.67	2.14	4.26	0.81	0.11	174.0	1239.8	951.6	3436.4	16.7
To54	1.56	4.08	7.8	1.50	0.11	70.5	1274.2	645.2	3529.3	14.8
To55	1.43	6.97	7.72	1.62	0.14	174.8	1033.2	602.2	2972.0	13.5
To56	1.51	3.12	5.43	1.87	0.13	117.5	241.1	247.3	650.1	3.8
To57	1.58	1.07	6.13	0.87	0.05	69.0	68.9	115.6	185.8	1.6
To58	1.48	12.19	7.37	1.25	0.09	142.7	551.0	884.4	2600.5	12.3
To59	1.65	9.84	7.23	1.10	0.09	117.1	344.4	314.5	743.0	4.7
To60	1.60	10.36	6.67	0.96	0.06	88.4	275.5	306.5	650.1	4.2

KEY:
Ti - Transect inside the floodplain
To- Transect outside the floodplain

Trans. - Transect
Bd - Bulk density
Mois - Moisture
CEC - Cation Exchange Capacity

Appendix 3c: Soil characteristics in irrigated agricultural areas

Trans.	Bd	Mois	pH	C	N	P	K	Mg	Ca	CEC
To27	1.16	18.57	7.87	1.32	0.10	87.1	2204.1	1201.6	5386.8	24.2
To28	1.42	4.75	7.75	0.56	0.08	38.0	723.2	491.9	1857.5	9.2
Ti32	1.39	5.74	8.02	0.16	0.04	313.6	1446.4	814.5	3900.8	17.9
Ti36	1.50	7.72	7.55	1.63	0.14	219.9	826.5	505.4	2321.9	10.2
Ti37	1.25	11.29	7.79	1.32	0.12	167.8	482.1	293.0	1207.4	6.1
Ti41	1.33	10.70	8.16	0.14	0.04	177.3	619.9	510.8	1857.5	9.4
Ti42	1.34	9.83	8.07	0.29	0.05	146.0	861.0	446.2	2507.7	11.2
To43	1.50	8.04	8	0.95	0.04	113.8	688.8	462.4	1857.5	9.2
To44	1.06	2.34	8.33	0.51	0.02	103.5	241.1	212.4	650.1	3.7
Ti46	1.40	7.48	8.05	0.62	0.04	165.6	757.7	569.9	2136.2	10.6
Ti47	1.26	7.84	7.69	0.54	0.06	196.1	964.3	639.8	2693.4	12.4
Ti48	1.11	14.23	7.34	0.99	0.10	165.0	929.8	637.1	2507.7	12.3
Ti49	1.16	22.95	7.72	1.20	0.08	211.2	792.1	349.5	2043.3	9.4
Ti50	1.18	18.73	7.44	1.52	0.11	148.8	447.7	483.9	1578.9	7.2
Ti51	1.17	22.03	7.25	1.62	0.10	174.5	585.5	387.1	1578.9	7.7
Ti52	1.26	10.57	8.44	0.56	0.08	212.3	964.3	817.2	2786.3	13.9
Ti61	1.38	9.46	7.4	0.42	0.07	182.9	1343.1	1188.2	3900.8	18.8
Ti62	1.61	8.23	7.13	0.10	0.05	231.6	1480.9	1010.8	3993.7	19.0
Ti63	1.68	9.04	6.41	0.69	0.09	160.0	1377.6	1172.0	3622.2	17.7

KEY:
Ti - Transect inside the floodplain
To- Transect outside the floodplain

Trans. - Transect
Bd - Bulk density
Mois - Moisture
CEC - Cation Exchange Capacity