SUSTAINING THE ALLIDEGHI GRASSLAND OF ETHIOPIA: INFLUENCES
OF PASTORALISM AND VEGETATION CHANGE

by

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ABSTRACT

Sustaining the Allideghi Grassland of Ethiopia: Influences of Pastoralism and Vegetation Change

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The Allideghi Wildlife Reserve in the Amibara District of Afar Regional State, Ethiopia, has international significance for harboring endangered Grevy’s Zebra and other wildlife dependent on grasslands. The reserve is increasingly used by pastoral people and their herds. Impacts of livestock on native vegetation include direct effects of grazing and indirect effects from livestock-facilitated dispersal of an invasive plant, Prosopis juliflora. The main research objective was to determine effects of pastoralism and vegetation change on prospects for sustaining the Allideghi Wildlife Reserve as grassland habitat for Grevy’s Zebra. Methods included use of driving surveys to quantify resource use by herbivores, vegetation analysis, and engagement with local people.

Resource-use patterns of livestock across the Allideghi grassland were often positively affected by proximity of water, while that for wild ungulates was often negatively affected by proximity of people. Livestock concentration at a major borehole
has created a large piosphere with concomitant reductions in herbaceous standing-crop, productivity, and species richness; plant species have shifted from grasses to forbs in severely grazed sites. Vegetation further from the borehole was resilient in response to moderate grazing pressure in terms of species composition and productivity.

Since being introduced at a nearby commercial plantation in the 1970s, *P. juliflora* has been dispersed to the Allideghi Wildlife Reserve via livestock; cattle, sheep, and goats eat the pods and deposit seeds in manure at settlements and favored foraging areas. *Prosopis juliflora* greatly reduced species richness and basal cover of native herbaceous vegetation in the Allideghi grassland. Analysis of remotely sensed images from the past 30 years indicated major land-use change in the district due to agricultural expansion as well as land-cover change due to *Prosopis* encroachment and heavy grazing. Recent efforts have been undertaken by various agencies to control *P. juliflora*, via harvest in the district, but this has yielded variable and often negative results.

Without a concerted effort to limit livestock grazing and control spread of *P. juliflora*, the future for the grassland and wildlife at the Allideghi Wildlife Reserve is grim. Agencies and policy makers need to promote science- and community-based approaches to help rectify the situation.
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CHAPTER 1
INTRODUCTION

Background and Problem Statement

Ethiopia is known for its biodiversity. Inventories reveal 277 species of terrestrial mammals, 862 species of birds, 201 species of reptiles, 63 species of amphibians, 150 species of fish, and over 7,000 species of plants (Hillman 1993a). Ethiopia is known as one of the global centers of endemism (Hillman 1993a). Endemics include 30 species of mammals, 16 species of birds, 10 species of reptiles, 30 species of amphibians, four species of fish and more than 1,000 species of plants.

Since 1966, Ethiopia has established nine national parks, three wildlife sanctuaries, eight wildlife reserves, and 18 controlled hunting areas (Hillman 1993a). Theoretically the different categories have different levels of protection; strict conservation in national parks and sanctuaries, but with multiple uses in reserves and controlled hunting areas. Regardless of the level of protection, however, almost all of these areas are facing problems. Many populations of wild animals have been declining with some becoming locally extinct (Hillman 1993a, Schloeder and Jacobs 1993). Some of the major problems impacting wild animals include habitat degradation or loss due to overgrazing by pastoral livestock, settlement, agricultural expansion, deforestation, uncontrolled fire, land-use conflicts with local communities, and poaching (Kebede 2001).

The Allideghi Wildlife Reserve (AWR) is situated in a semi-arid region of the country. It is over 1,800 km² in size. An important part of the reserve is the Allideghi Plain. It is located in Afar Regional State in the north-eastern part of the country within
the district (wereda) of Amibara (Figure 1.1). The remaining mountainous part of the reserve is located in Oromia Regional State. In Ethiopia, the Afar people (who are predominantly pastoralists) reside in the Afar region. The Afar people keep large herds of livestock primarily for milk production and wealth accumulation. They traditionally practiced an efficient land-use and livestock management system primarily dependent on mobility (Getachew 2001). However, conflicts with other neighboring tribes, population growth, and loss of access to water sources and grazing areas due to agricultural expansion and other developments forced them to change their migration patterns (Piguet 2002). The Afar started to settle in places such as the AWR over three decades ago. The major land uses in the Allideghi area include extensive livestock grazing, concentrated settlements, and wildlife refuges.

The AWR is not legally gazetted like many other protected areas (except Awash and Simen Mountains National Parks), but the main purpose of its establishment has been to serve as a buffer zone for neighboring more protected areas such as Awash National Park (Hillman 1993b). The AWR provides critical habitat for the endangered Grevy’s Zebra (Equus grevyi), Beisa Oryx (Oryx beisa), Sommering’s Gazelle (Gazella soemmerringi), Gerenuk (Litocranius walleri), Lesser Kudu (Tragelaphus imberbis) and others (Hillman 1993b). The AWR supports the northernmost population of Grevy’s Zebra in Ethiopia (Moehlman 2002, Moehlman et al. 2008).

According to local informants, the Afar pastoralists traditionally used the AWR for grazing during rainy periods when there was enough drinking water in the form of ephemeral ponds and streams. However, during the past decade, the Afar have established permanent settlements in the AWR and started to herd livestock in the area all
year. This is attributable to the development of boreholes that provide permanent sources of water (A. Kebede, pers. obs.).

Recently, invasive species have created additional ecological challenges for AWR (Kebede 2001). The exotic woody plant called honey mesquite \(\text{Prosopis juliflora}\) (Swartz) DC. has spread in the AWR as well as in the surrounding pastoral grazing lands (A. Kebede, pers. obs.). The species has the potential to spread to nearby Awash and Yangudi-Rasa National Parks. Since pastoralist herders still move livestock in search of forage, and livestock are vectors in the dispersal \(\text{Prosopis}\) species (Archer et al. 1988, Brown and Archer 1989, Geesing et al. 2004), protected areas may be at risk of losing habitat for wild animals. The Afar and other pastoralists continue to lose other grazing lands, which, in turn, will accelerate pressure on protected areas (Kebede 2001).

The Equid Action Plan (Moehlman 2002) noted large knowledge gaps about the habitat status of Grevy’s Zebra in Ethiopia in general, and at AWR in particular. Therefore, this research was designed to answer questions about the sustainability of AWR in relation to the maintenance of critical wildlife habitat.

**Literature Review**

*Wildlife in Ethiopia*

History of Wildlife Conservation. Before the establishment of protected areas in Ethiopia, Emperor Menilik II declared the first wildlife conservation law in 1909. This law prohibited killing of wildlife, especially elephants, without the permission of hunting authorities who were appointed by the Emperor. Larger mammals such as elephant,
buffalo, lion, leopard, and other big game had been actively hunted by the upper classes and their populations were beginning to dwindle.

Thirty-five years later, the Ethiopian Ministry of Agriculture passed a wildlife conservation proclamation in 1944 to regulate wildlife hunting through a division in the Ministry of Agriculture (Negarit Gazetta 1944). However, there was no institution established to conserve and manage the wildlife resources of the country until 1964 when the Ethiopian Wildlife Conservation Organization (EWCO) was established. The EWCO was ultimately legally declared in 1970 with order number 65/70 to manage all protected areas in the country.

In 1969, two national parks (Awash and Simien Mountains) were established and legally gazetted. After this time, many other protected areas were established. Ethiopia now has nine national parks, three wildlife sanctuaries, eight wildlife reserves and about 18 controlled hunting areas (the number of controlled hunting areas differs from time to time) covering about 3.2% of the country.

Since 1908, 15 wildlife laws and regulations have been passed on various wildlife issues at the national level (not including statutes passed by regional governments). Of these 14 laws and regulations, seven are still in force. These include:

1. Establishment of the Awash National Park - order 54/69
2. Establishment of the Simien Mountains National Park - order 59/69
3. Conservation of Wildlife - Legal Notice 416/72
4. Conservation of Wildlife (amendment) - Legal Notice 445/74
5. Conservation and Development of Forest and Wildlife Resources -
   Proclamation 192/80. (This proclamation is repealed only concerning issues of
   forests).

6. Amendment on the Establishment of the Biodiversity Conservation and
   Research Institute - Proclamation 167/99

7. Wildlife Development Conservation and Development Policy and Strategy -
   March 2005

8. Establishment of Wildlife Protection Authority – April 2008

   The recent Policy and Strategy of 2005 will serve as a basis for future wildlife
   matters at the national level. In addition to these domestic actions, the EWCO was
   responsible to ensure the Ethiopian government’s commitment to international treaties
   and conventions concerning wildlife. These are: International Union for Conservation of
   Nature and Natural Resources (IUCN), Convention on International Trade in Endangered
   Species (CITES), World Heritage Convention (WHC), and the Convention on Biological
   Diversity (CBD).

   After the establishment of EWCO in 1964, there were more aggressive efforts to
   establish protected areas and develop their infrastructure. These included policies that
   excluded the participation or involvement of local communities in wildlife conservation.
   Even after establishment of protected areas, the local people did not benefit from this
   sector in general and began to develop negative attitudes towards wildlife and/or wildlife
   conservation (Tessema 2003). This had serious consequences during the downfall of the
   military government of Ethiopia in 1991 when most of the national parks’ infrastructure
   was destroyed, properties looted, and wild animals killed (Gebre-Michael et al. 1992).
Bale and Abijata-Shalla Lakes National Parks and Senkele Swayne's Hartebeest Sanctuary were a few of the protected areas affected at that time. This problem reminded the authorities to revise the old approaches of wildlife conservation and cultivate support from local communities via new ideas such as community participation. The idea of community participation in wildlife management was introduced around 1995 from the experience of other African countries such as CAMPFIRE of Zimbabwe and Administrative Management Design (ADMADE) of Zambia (Hackle 1999, Murombedzi 1999). Since 1995, participatory management and benefit sharing for local communities has become the main agenda to win their support and approval of conservation activities (Tessema 2003).

The new federal government, established in 1991, embarked on a program of decentralization and regionalization. Nine regional states, Addis Ababa Administration, and the Dire Dawa Administration Council were formed. In 1996, most protected areas were handed over to the regional governments except those which fell in more than one region. These remained under the control of the federal government. These include Awash National Park, the Senkele Swayne’s Hartebeest Sanctuary and the Babile Elephant Sanctuary. Yangudi Rassa National Park is also under the control of the federal government even though it is totally inside the Afar Region. This was because the Afar region was not capable of administering the park at the time.

The status of EWCO, which was semi-autonomous under the Ministry of Agriculture, was down-graded to a department level - Ethiopian Wildlife Conservation Department (EWCD) - since 2004. Recently, during April 2008, the EWCD was upgraded to the Ethiopian Wildlife Protection Authority (EWPA) under the Ministry of
Culture and Tourism. It has been speculated that this upgrade will allow EWPA to have a greater role in protecting the wildlife resources of the country.

Wildlife and their habitats are still facing a number of problems despite the conservation and development efforts made by federal and regional governments (Jacobs and Schloeder 2001). The major problems include: loss of biodiversity (e.g. local extinction of Grevy's Zebra from Awash National Park, hybridization of critically endangered endemic species [e.g. Simien wolf (Canis simensis) with domestic dogs], and habitat deterioration due to human settlement, expansion of agriculture, deforestation, and intensive grazing.

Grevy's Zebra. Of the seven species of equids remaining in the world, three are zebras. These include the Plain's (or Burchell's) Zebra (Equus quagga), the Mountain Zebra (E. zebra), and Grevy's Zebra (E. grevyi; Hack and Rubenstein 1998, Moehlman 2002, IUCN 2008). The Plain's Zebra is the most abundant and widespread, inhabiting tropical grasslands and savannas of East Africa down through the scrubby woodlands of the Zambezi Region to the grasslands of South Africa. The Mountain Zebra inhabits a temperate climate in the mountainous regions of Namibia and southern South Africa. Grevy's Zebra is currently found in the semi-arid zones of Ethiopia and Kenya and possibly Sudan. All zebras feed mainly on grasses or grass-like plants (Hack and Rubenstein 1998).

The influence of anthropogenic factors has led Grevy's Zebra to marked contractions of their range since the last century (Bauer et al. 1994, Williams 2002). Historically, Grevy's Zebra were believed to be found in semi-arid areas of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, and Sudan (Figure 1.2; Kingdon 1979, Williams
2002). However, historical documentation indicated that they were observed only in the semi-arid areas of Ethiopia, Kenya, Somalia, and Sudan (Figure 1.3; Bauer et al. 1994). Currently this species is only found in central and southern Ethiopia and northern Kenya (Figure 1.2; Williams and Ginsberg 1998, Moehlman 2002, Williams 2002, Williams et al. 2003). Grevy’s Zebra has been listed as an Appendix I species on Convention on International Trade in Endangered Species of Flora and Fauna (CITES) since 1979. This status provides some protection as it limits the international trade in Grevy’s Zebra and body tissues and hides (Williams and Ginsburg 1998, Williams et al. 2003). Due the decline of their numbers and substantial reductions of their range, Grevy’s Zebra is also classified as an endangered species on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (Moehlman et al. 2008). In Ethiopia, it is legally protected and the government of Kenya is currently revising its conservation status from a game animal to a protected animal (KWS 2008).

The global decline in the number of Grevy’s Zebra from 1980 to 2007 is estimated to be 68% (Moehlman et al. 2008). The global population has declined from an estimate of 15,000 in the late 1970s to the current estimate (Ethiopia and Kenya) ranging from 1,966 to 2,447 (KWS 2008, Moehlman et al. 2008).

In Ethiopia, the decline of Grevy’s Zebra from 1980 to 2006 has been approximately 93% (Rowen and Ginsberg 1992, Moehlman et al. 2008). From 1995 to 2002, the decline was approximately by 78% from the estimate of 500-600 animas to 110 individuals (Thouless 1995a, 1995b, Williams et al. 2003). From 2003 to 2006 there may have been a slight increase in the national population (Moehlman et al. 2008).
In Kenya, the population of Grevy’s Zebra has also decreased drastically both in protected and unprotected areas due to the growing human populations and the associated problems (Rubenstein 2001, Williams 2002). A survey in northern Kenya indicated a 40% decline of Grevy’s Zebra population from the estimate of 4,276 animals in 1992 (KREMU 1989, Rowen and Ginsberg 1992) to an estimate of 2,570 individuals in 2000 (Nelson and Williams 2003). In 2004, the Kenyan population was reported at between 1,600 and 2,000 individuals (Williams and Low 2004). By 2007, the population was estimated between 1,838 to 2,319 animals (Mwasi and Mwangi 2007). An anthrax outbreak which occurred between December and March 2006 in the communally owned pastoralist area in southern Samburu, Kenya killed 53 Grevy’s Zebra (Muoria et al. 2007). However, the recent data indicate that the Kenya population of Grevy’s Zebra may be stabilizing and slowly increasing (Moehlman et al. 2008)

Both in northern Kenya and Ethiopia, it is likely that Grevy’s Zebra are dependent on resources used by pastoral people and their livestock. With increasing human and livestock populations, access to forage and water has become more difficult and Grevy’s Zebra have lost habitat (Hack and Rubenstein 1998, Williams 2002). Studies in Kenya indicate that Grevy’s Zebra recruitment is adversely affected by pastoralists and livestock (Williams 1998, Nelson and Williams 2003). In Ethiopia, the decline is attributed to illegal hunting with automatic weapons (Williams et al. 2003). Overall, killing, loss of access to critical resources due to competition with livestock, and decline of these resources due to overexploitation have a direct effect of the decline of Grevy’s Zebra (KWS 2008).
In Ethiopia, there has been a serious decline of Grevy’s Zebra in all three protected sites: AWR (central Ethiopia), Yabello Sanctuary and surrounding areas (southern Ethiopia), and in the Chalbi Wildlife Reserve (also in southern Ethiopia; Thouless 1995b). The AWR was primarily known for its population of Grevy’s Zebra that thrived on the extensive, perennial grasslands. The Grevy’s population at AWR appears dynamic. From a 1995 aerial survey, it was estimated that there were 411 Grevy’s Zebra in the AWR (Thouless 1995a). A survey combining aerial methods and interviews of pastoralists in 2002 indicated a population of 54 (Williams et al. 2003). More recent ground surveys suggest that the population may have increased (Moehlman et al. 2008). The Grevy’s population in the AWR is geographically isolated and represents the northern tip of the species distribution (Figure 1.2). Recent population estimates in Kenya and Ethiopia indicate that only 6% of the remaining animals are found in Ethiopia and out of this, the majority occur in the AWR.

At the Allideghi Plain, Grevy’s Zebra and other wild animals survive by sharing resources with pastoralists, and thus the lives of the people and wild animals are intertwined. The major problems which affect Grevy’s Zebra in Ethiopia overall appear to be poaching, habitat degradation and loss, limited access to water, and competition with the pastoral people and their livestock for critical resources (Williams 2002).

Pastoralism in Ethiopia

History of Pastoralism. Drylands cover about 40 percent of the earth’s surface (UNDP 2003) and are characterized by low and highly variable precipitation (UNDP 2003, McCarthy et al. 2004). Mobile pastoralism has been the key indigenous production

The key strategies to mitigate exposure to erratic precipitation is the ability to move livestock to different foraging areas (McCarthy et al. 2004, Omosa 2005) and to manage risk by having mixtures of livestock with differing resistance to disease and drought (Köhler-Rollefson 2005).

Earlier, pastoralism was seen as an evolutionary phase following hunting-gathering in human history which ultimately led to sedentary way of life, mainly agriculture (Blench 2001, UNDP 2003). However, historical research indicates that agriculture evolved before pastoralism in most of the Old World except in Africa (Blench 2001). Other archaeological studies indicate that domestication of animals took place at the same time, or later, than domestication of plants (UNDP 2003).

Because rangelands have low and variable productivity per unit area, they are often managed as “common access” resources rather than privatized. Thus, pastoral areas are synonymous with communal access and management. The concept of the “tragedy of the commons” (Hardin 1968) has been often applied to pastoral areas with reference to common property rights (Aredo 2004). The “tragedy of the commons” holds that land held in common will ultimately be overgrazed in the absence of local rules and regulations governing access (UNDP 2003). However, all common grazing lands are not
necessarily poorly managed. Traditional systems of resource allocation and control can be greatly undermined by population growth, governmental interference, and increase in livestock numbers without the requisite animal off-take for market (Coppock 1994).

Pastoralism is still being practiced in arid environments of Africa, the Middle East, Central Asia, Mongolia, the highlands of Tibet, the Andes, arctic Scandinavia, and Siberia (Fratkin 1997). In Africa, pastoralists are found throughout the arid and semi-arid regions, having 12 to 16% of the total population (Omosa 2005). In eastern Africa and the Horn, different forms of pastoralism are practiced, ranging from pure nomadism without settled habitation and cultivation to settled modes of life which combine transhumance and cultivation (Markakis 2004).

In Ethiopia, pastoralism is one of the oldest socio-economic systems (Mussa 2004). There are about seven million pastoralists (12% of the total population) representing about 29 different ethnic groups occupying approximately 60% of the country's land area (Mussa 2004, Ethiopia Country Profile 2005). A large portion of pastoralists are found in the dry lowlands of the east, southeast, and southern part of the country. These lowlands occur below 1500 masl (Coppock 1994). A survey in 2003 indicated that there are 35 million cattle, 25 million sheep, and 18 million goats in Ethiopia, many of which occur in pastoral areas (Ethiopia Country Profile 2005). In Ethiopia, it is obvious that livestock production is an important component of the national economy. According to Coppock (1994), cattle and sheep from the lowlands comprised over 90% of live-animal- exports of the country during the preceding decade. The revenue obtained from the export of livestock and livestock products is one of the major sources of foreign exchange (Coppock 1994, Solomon et al. 2003).
Afar pastoralists have historically occupied the northern part of the Great Rift Valley which runs through the eastern Horn of Africa in the northeastern Ethiopian lowlands, the eastern third of Eritrea, and northern and central Djibouti (Shehim 1985, Unruh 2005). The Afar Region, where this study was conducted, is one of the pastoralist areas of Ethiopia located in the northeast of the country bordering with Eritrea in the north and Djibouti in north east (Haile and Roy 2006). The Afar pastoralists primarily depend on livestock for food and asset accumulation. They traditionally have kept large herds of camels, sheep and goats, and cattle, along with donkeys (Getachew 2001). Some Afar have more recently integrated farming, commerce, and wage employment with their pastoral livelihoods. The population of the Afar is about 1.1 million based on the 1996 national census (Tesfay and Tafere 2004, Haile and Roy 2006).

The rights of herders to access traditional grazing areas are generally eroding everywhere in Africa (McCarthy et al. 2004). In Ethiopia, Tanzania, Uganda, and Kenya, pastoral peoples tend to occupy public or state owned land and explicit rights of pastoralists to exclusive use of land or water is not guaranteed (Markakis 2004). In Ethiopia, a 1975 proclamation gave possessory rights to nomads over the lands they customarily graze, but there has been no formal decree for implementation (Hogg 1990). The Afar pastoralists are exercising their rights in the Allideghi region based on the existing pastoral philosophy in which land belongs to community members and is equally divided among all clans based on resource potential (Hundie 2006).

During the last decade, the Afar pastoralists have experienced major droughts every three years (Getachew 2001, Tesfay and Tafere 2004). Their grazing land has been reduced by the establishment of agricultural plantations in the area since 1962 along the
Awash River Valley (Shehim 1985). The effectiveness of pastoralism is declining dramatically since their mobility is restricted by expansion of agriculture, private ranches, nature reserves, and infrastructure on their traditional grazing lands (Fratkin 1997, Getachew 2001, Lybbert et al. 2001, Gebre 2004, Markakis 2004, Tesfay and Tafere 2004). As a result, some of the Afar people are now settling in semi-permanent centers (Omosa 2005). Traditionally, there are inter-clan conflicts and conflict with the surrounding tribes, especially Somalis, mainly over pasture and water. Thus, ethnic conflicts also restrict the mobility of the Afar (Tesfay and Tafere 2004, Omosa 2005, Unruh 2005). As a result of all these pressures, a shift from nomadic pastoralism to agro-pastoralism has occurred in recent years (Markakis 2004, Tesfay and Tafere 2004). Overall, poverty and destitution are common outcomes for such people (Fratkin 1997).

In Ethiopia, most agriculture and natural resource policies were formulated on the basis of a sedentary way of life. This has resulted in relatively less development and political power among the pastoralist communities (Mussa 2004, Haile and Roy 2006). Lack of permanent settlement and communal resource tenure has made it difficult to provide pastoral communities with basic education and health services (Haile and Roy 2006). In the Afar Region for instance, formal education (25% enrollment), access to health care (31% coverage), access to veterinary services, access to clean drinking water (17% coverage) and availability of other basic services are poor (Haile and Roy 2006). Currently, government development policies and programs have started to be more sensitive to pastoralism. One example is the passage of pastoral development legislation and establishment of a Pastoral Affairs Standing Committee within the federal parliament.
An alternative way of providing mobile education and health services is also underway in some places as implemented by NGOs (Haile and Roy 2006).

**Impact of Ungulate Grazing.** The multiple use values and health of rangeland are often determined by the amount of vegetation left after grazing (Holechek et al. 2000). Traditional rangeland management practices are based on adjusting the stocking rate to maintain a grass composition, cover, and biomass suitable for meeting management objectives (Brown and Archer 1999). Some consider large ungulates as an integral component of grassland and savanna ecosystems (Painter and Belsky 1993) and grazing as an essential process that characterizes rangelands (Holechek et al. 2000). However, prolonged and heavy grazing regimes can lead to desertification, woody plant encroachment, and deforestation (Asner et al. 2004).

Thus, the overall effect of grazing on plant performance (i.e., positive or negative) is a critical controversy in rangeland management (Dyer et al. 1993, McNaughton 1993, Painter and Belsky 1993, Patten 1993). Painter and Belsky (1993) argued that the concepts of herbivore optimization and over-compensation of plants in response to grazing have been used to justify heavy livestock grazing on rangelands. According to Dyer et al. (1993), low levels of herbivory increases plant productivity, whereas high levels of herbivory can cause large reductions in productivity, and ultimately, plant mortality (Holechek et al. 2000).

Others argue that heavy grazing can negatively affect structure and function in any ecosystem (Archer 1994, Fleischner 1994, Kerley 2000) and result in great ecological damage (Fleischner 1994). Grazing can change plant cover, remove soil litter, and causes soil disturbance (Fleischner 1994, Brown and McDonald 1995). Intensive grazing can
reduce the productivity of desirable grasses (Holechek et al. 2000) and encourage the proliferation of unpalatable forbs and shrubs (Van Auken and Bush 1997). Heavy grazing can also reduce the extent, frequency, and intensity of fires by altering the quality and quantity of fuels available for combustion (Hobbs 1996, Van Auken and Bush 1997).

There is evidence, however, that moderate grazing can increase net primary productivity, and that some types of plants can benefit from the presence of grazing animals (McNaughton 1993). McNaughton (1993) also mentioned that there is a difference between natural grazing systems (wild ungulates) and agricultural ones (livestock) both in terms of population density and degree of mobility. Patten (1993) illustrated that elk grazing in Yellowstone National Park caused some areas to be dominated by exotic grasses. Although the primary goal of grazing management is to maximize photosynthetic activity with controlled defoliation (Holechek et al. 2000), some conclude that overcompensation and optimization of net primary productivity rarely occur and may have little or no applied significance (Painter and Belsky 1993).

Pastoralism and Wildlife. Mobile pastoralism has been a form of land use that is well-adapted to the challenges of dry lands to maintain sustainable and productive livelihoods for people (UNDP 2003). In some parts of Africa and Central Asia, pastoralist herders still interact in one way or another with significant wildlife populations; this includes hunting wild animals and dealing with the predation of livestock as well as the effects of competition between livestock and wild herbivores for forage and water (Blench 2001). Pastoralists of eastern and southern Africa have a significant dependence on wildlife and their habitats for livelihood and food security (Lybbert et al. 2001, LWAG 2002). Over many centuries, pastoralists and wildlife have
co-existed on African rangelands, although much of this history has been characterized by pastoral populations of people and animals that have been relatively small and widely dispersed (Boyd et al. 1999). Traditional pastoralism with high levels of mobility maintain native plant and animal species more so than crop cultivation systems (Maitima et al. 2004) and may sometimes enhance biodiversity (Reid et al. 2003). This suggests that integrated livestock-wildlife systems can be more productive than one or the other system considered alone in east Africa (Reid et al. 2003). Based on 30 years of research in Uganda, Kenya, and Tanzania, areas with moderate livestock grazing have been observed to support more plant and wildlife species than ungrazed areas (Maitima et al. 2004).

Many pastoralists have been deprived of the valuable land and water resources by external and internal forces; one consequence has been that their mobility has been greatly reduced (Coppock 1994). This has led to high-density settlements which can result in local degradation of habitats and a massive shift to agro-pastoralism, both of which may not be compatible with wildlife conservation (Reid et al. 2003, Markakis 2004). Currently, some wildlife species are best conserved in places having no people and no livestock (Reid et al. 2003). For instance, the distribution of black rhinos is negatively affected by the presence of livestock in the Masai Mara National Reserve (Walpole et al. 2003). Protected areas are vital refuges for many threatened plants and animals as natural habitats are declining and face increasing pressure, while some conservation policies are disadvantageous for local people (id21 Insights 2005). Thus, the ultimate goal of enhancing the living standards of pastoralists while conserving local biodiversity is emerging as the biggest challenge (Fox et al. 2002).
Declines of wildlife and the degradation of wildlife habitats in the semi-arid savannas of Africa are commonly attributed to the growth of agro-pastoral populations, impacts of livestock grazing, and the spread of subsistence cultivation (Kock et al. 2002, Homewood et al. 2001). Urban and agricultural expansion threatens protected areas via fragmented habitats (id21 Insights 2005). Increased livestock numbers result in resource competition between livestock and wild animals (Fox et al. 2002). Thus, the conflict between wildlife managers and livestock owners is growing (Boyd et al. 1999, Fox et al. 2002).

In Ethiopia, most protected areas including the AWR are situated in the arid and semi-arid rangelands of the country at lower elevations. Bale and Simen Mountains National Parks, in contrast, are in highland zones (WCMC 1991, Gebre-Michael et al. 1992, Tessema 2003). Many of these protected areas have suffered from human encroachment with negative effects of permanent settlement around their margins (WCMC 1991). The resettlement policies, land annexation, and inter-tribal conflicts which restrict long-distance mobility of pastoralists have created new pressures for protected areas since they often have the few remaining parcels of natural resources that are essential for pastoralists to survive (Getachew 2001, Jacobs and Schloeder 2001).

Conservation efforts in Ethiopia have traditionally followed a “strict conservation concept” that excluded any form of indigenous human presence in the national parks. These efforts illustrate a complete ignorance of the numerous customary use rights that indigenous people shared (Gebre-Michael et al. 1992, Jacobs and Schloeder 2001). During the downfall of the Ethiopian military government in May, 1991, most protected areas in the country were affected by the surrounding people who considered wildlife as a
problem and competitors for land (Gebre-Michael et al. 1992). This experience has led the current government to revise the wildlife policy so that indigenous people share benefits from protected areas (Tessema 2003).

However, there is a need to balance pastoralism and conservation of natural resources in protected areas (LWAG 2002). Limiting the density of settlements would foster the positive effects of pastoralism on wildlife (Reid et al. 2003). If governments provided incentives for pastoral communities to maintain their traditional lifestyles and livelihoods that are compatible with wildlife, these polices would support and improve the livelihood of the people (Reid et al. 2003, Markakis 2004). In Namibia and Zimbabwe, community-based wildlife management practices have brought significant employment and income-generating opportunities, empowerment, and governance impacts to some remote communities through wildlife tourism (LWAG 2002).

*Prosopis Juliflora in Ethiopia*

Ecology. *Prosopis juliflora*, or mesquite, is an invasive evergreen plant which is native to Central and northern South America and the Caribbean and has spread to North America (Pasiecznik et al. 2004, Mwangi and Swallow 2005, El-Keblawy and Al-Rawai 2007). It has been introduced to Australia, Asia, the Middle East, the Caribbean, Latin America, the Virgin Islands, and Africa. Within Africa, major destinations have included Morocco, Senegal, Niger, Kenya, South Africa, Tanzania, Sudan, Uganda, Ethiopia, and Eritrea (Pasiecznik et al. 2001, ICRAF 2007).

According to elders, *P. juliflora* was introduced in the Middle Awash Valley, Ethiopia, in the 1970s by a foreigner who lived at the Melka-Werer Cotton Plantation,
near the AWR. It was started as a garden plant around the person’s office and residence (UNDP Emergencies Unit for Ethiopia 2002). Even though it was first incorporated into home gardens, it then become established in the natural landscapes and has significantly affected the ecology of many areas, especially in the Afar Region.

*Prosopis juliflora* is an ideal invader on disturbed or overgrazed lands (Geesing et al. 2004, Andersson 2005). It is a fast-growing plant on a wide range of soils and is moderately salt tolerant (Silva 1986, Mahgoub et al. 2005). It grows under very high temperatures, tolerates mild frost and survives in areas with very low precipitation and poor soils (Muthana 1986, Silva 1986). The seed of *P. juliflora* has excellent viability for years (Shiferaw et al. 2004) and germinate during favorable conditions such as flooding and rainfall (Pasiecznik et al. 2001, Geesing et al. 2004). It is deeply rooted plant with significant drought tolerance (Mahgoub et al. 2005, Herrera-Arreola et al. 2007), which is an advantage for obtaining deep sources of soil water in the absence of surface water (Holechek et al. 2000, Pasiecznik et al. 2001, Andersson 2005). Thus, *Prosopis* is an excellent competitor once it has established and develops deep roots (Nilsen et al. 1986). The leaves of *P. juliflora* have high tannin content and are unpalatable for livestock except the new shoots (Pasiecznik et al. 2001). However, the pods contain a high level of sugar and protein content and are highly palatable to livestock (Mendes 1986, Pasiecznik et al. 2001, Geesing et al. 2004).

Even though *P. juliflora* can usually invade disturbed areas of grasslands, its successful seedling establishment is inhibited in areas where grass density is high (Andersson 2005). Van Auken and Bush (1988, 1989, 1997) as well as Bush and Van Auken (1995) demonstrated the negative impact of grasses on the growth of *P.*
glandulosa when it is not browsed. However, grazing or clipping of grass can reduce the competitive ability of grasses, and in this situation Prosopis can grow to the same size as when grown in the absence of grass. In sparse stands, Prosopis competes little with herbaceous plants (Dahl et al. 1978). This suggests that Prosopis will be more successful in grazed sites than ungrazed sites and that grazing may promote the invasion of this plant in grasslands. According to Brown and Archer (1999) and Geesing et al. (2004), the increased abundance of Prosopis in many areas has been attributed to heavy grazing by livestock. However, Prosopis can also germinate and grow in intact, native grasslands (Meyer and Bovey 1982, Bush and Van Auken 1991). In these situations, the growth rate can be slow, as influenced by the negative effects of neighboring grass species, fire, and herbivory. Once its roots are established and shoots are elevated above the grass interface, its survival rate increases markedly (Van Auken and Bush 1997).

Rates and patterns of seed dispersal may be the primary determinants of encroachment by Prosopis on landscapes in semiarid regions (Brown and Archer 1989). The migration and establishment of P. juliflora is generally believed to be enhanced by overgrazing, reduction of naturally occurring fires, and the spread of seeds by livestock and rodents (Geesing et al. 2004). The primary cause of P. juliflora dispersal is from seeds carried in the digestive tract of animals and excreted on the soil surface (Muthana 1986, Geesing et al. 2004, Shiferaw et al. 2004, Andersson 2005). Livestock appear to be an effective vector of P. juliflora seed dispersal since they scarify the seeds and deposit them in nutrient-rich media (dung) away from the parent plant (Silva 1986, Shiferaw et al. 2004, Andersson 2005). Livestock grazing reduce herbaceous interference or competition and the probability of fire and allows Prosopis to establish successfully
(Archer et al. 1988, Archer 1989, Kneuper et al. 2003). In addition, large herds of domestic livestock disrupt the tight coupling of soil and plant processes and lead to a decline in the cover of the herbaceous layer in semi-arid grasslands (Schlesinger et al. 1990). Thus, minimizing livestock dispersal of seed and maintenance of an effective fire regime may be crucial for sustaining herbaceous composition and production in grazed systems prone to invasion by unpalatable woody plants (Brown and Archer 1989).

The leaves of *P. juliflora* contain water soluble allelopathic substance L-tryptophan (Nakano et al. 2003), but the allelochemicals in the leaves cause flavor aversions and other negative digestive consequences in lambs (Baptista and Launchbaugh 2001). These chemicals also inhibit seed germination and retard seedling growth of adjacent grasses (Al-Humaid and Warrag 1998). Invasion of *P. juliflora* reduce aboveground grass production and retard seedling growth of grasses (Singh et al. 1991, Al-Humaid and Warrag 1998, Mwangi and Swallow 2005), decrease native species diversity (El-Keblawy and Al-Rawai 2007), inhibit seed germination of grasses and reduce grass cover (Al-Humaid and Warrag 1998). Consumption of *P. juliflora* causes “twisted head disease” in cattle (Figueiredo et al. 1996). Its pollen is also a major cause of 13 human allergens (Killian and McMichael 2004).

However, other studies indicate that *P. juliflora* has a number of values for humans and animals. It is a nitrogen-fixer and can be used for intercropping with other plants to improve soil nitrogen content and forage quality (Lima 1986, Verinumbe 1991, Mahecha et al. 1999, Herrera-Arreola et al 2007). Pasiecznik (2001) and Duke (1983) mentioned the value of *P. juliflora* as food for people and livestock, as medicine, as a provider of nectar for bees, and utility as fuel wood by virtue of its fast growth, drought
resistance, and remarkable coppicing ability. However, its establishment outside managed agricultural systems presents a considerable threat as an invasive woody weed (Pimentel et al. 1999).

Dispersal. As previously mentioned, *P. juliflora* was introduced in the Middle Awash Valley, Ethiopia, in the 1970s. The local spread of the species has been impressive, with large areas now covered by mono-specific stands, with no herbaceous cover in the understory (A. Kebede, pers. obs). Key informants state that pastoral livestock have been important in the dispersal of *P. juliflora* off the Melka-Werer area. Animals feed on cotton residues and consume pods of *P. juliflora* from the surrounding areas. As animals then moved to other grazing area, they distributed seeds (A. Kebede, pers obs.). Some now consider *P. juliflora* as a major threat to Ethiopia’s rangelands while others consider it as a beneficial source of fuel wood because of its fast growth (Rezenom, Ethiopian Agricultural Research Organization (EARO), pers. comm.)

Lyons and Miller (2000) noted that despite the importance of many invasive species in eastern Africa, the scant knowledge that has been accumulated is often not sufficient for management in most cases. Hence, the impact of *P. juliflora* on the structure and function of ecosystems needs to be examined. According to Lyons and Miller (2000), the impacts of invasive species need investigation to provide information for early warning systems for intervention before irreversible environment degradation occurs.

Management. *Prosopis juliflora* is a fast growing and an aggressive species that is not easily eliminated from a site once established (Sharma and Dakshini 1998). Once such plants have become established, fire or anthropogenic modification (i.e., herbicide,
mechanical manipulation) may drive the system back toward a grassland configuration, but the conversion may be short-lived (Archer et al. 1989). As mentioned earlier, some of the features that make *P. juliflora* difficult to control include: the potential of the species to produce abundant and long-lived seeds disseminated by livestock and wildlife, the germination potential of the seed over a wide range of environmental conditions, and the ability of mature plants to re-sprout (Geesing et al. 2004, Shiferaw et al. 2004).

Thus, the choice of method to control *Prosopis* is very complex (McDaniel et al. 1982). Reduction of plants has been tried with machines, herbicides, and prescribed fire, yet none have had more than temporary results (Archer 1989, Heady and Child 1994). Areas cleared in the past either by mechanical or chemical methods generally have been re-infested with seedlings and re-sprouts that have developed into multi-stemmed bushes (Steinberg 2001). However, herbicides, mechanical treatments and regular prescribed burning can control the young plants better than the competitive effects of the native species since *Prosopis* establishes in areas where there is grazing pressure (Meyer and Bovey 1982).

People and Conservation. An important part of conserving the natural environment has been through establishing protected areas (Gorkhali 1986). In Africa, the policy of establishing protected areas was based on the western model of protection to isolate valuable landscapes from human impact (Ghimire and Pimbert 1997). Many protected areas were developed as wilderness preserves for public recreation without permanent human habitation or extractive use (Kemf 1993). Local communities were forced to leave areas where they had lived for centuries (Kemf 1993, Slavin 1993). However, approaches to conservation of natural resources have undergone major changes
to integrate the local communities in the planning and decision making process. Managers have realized that conservation efforts that are not supported by the local people are bound to fail (Martinet and McNeely 1992).

There has been little recognition or understanding of the relationship of local communities to biodiversity, including their knowledge and use of local species, their philosophy of living with nature, or the functional importance of biodiversity in livelihood (Kothari 1994). The knowledge of local people in interpreting and conserving natural resources is tremendous (Angeles 1992, Cordell 1993, Peralta 1994). Thus, the greatest challenge managers of protected areas face is to win the support of people living around these areas (Lamprey 1990).

Participation of local communities in the planning and management of natural resources is widely considered as a means of sustaining protected areas (De Boer and Baquete 1998). One of the guidelines for preparing protected area management plans is to build methods into the system for delivering benefits to local people (McNeely and Thorsell 1991). Another equally critical dimension is the procedural one of including local people in decision making and co-management of protected areas (Lewis 1993). Involving local people in conservation, management and policy making of protected areas gives them a sense of ownership. Sound management plans require community participation, which in turn requires governments to gain community trust. Community trust can only be obtained when there is concrete evidence that the protected area could be benefit local residents (Craven and Wardoyo 1993, Lewis 1993). Thus, the perceptions of local people must be understood in order to have them involved in planning and implementing conservation or management efforts (Hackle 1999).
Research Objectives

General Objective

The objective of this study was to determine the effects of pastoralist activities and vegetation change on prospects for sustaining the Allideghi grassland for future survival of a viable population of Grevy’s Zebra in the region.

Specific Objectives

1. To determine the spatial and temporal patterns of resource use by livestock and large wild herbivores at Allideghi Wildlife Reserve.
2. To determine the direct effects of livestock grazing on the productivity and species composition of herbaceous vegetation and assess the extent to which herbaceous vegetation can recover from livestock impacts.
3. To determine the indirect effects of livestock on the herbaceous vegetation as mediated by changes in woody vegetation, with a focus on *P. juliflora*.
4. To determine the attitudes of the local communities towards *P. juliflora* encroachment and management
5. To determine the attitudes of the local communities and representatives of relevant institution towards wildlife conservation in the Allideghi area.

Study Area

Location

The AWR has a semi-arid climate. The landscape is dominated by a large alluvial plain with mountains rising along the eastern border. The AWR is located about 280 km from Addis Ababa in the Ethiopian Rift Valley between latitudes 8° 92’ and 9° 48’ and longitudes 40° 25’ and 40° 63’. The AWR covers about 1,832 km² (WCMC 1991).
The AWR is contiguous with Awash West Wildlife Reserve to the west (which is adjacent to the Ethiopia's oldest national park, Awash National Park), and the Afdem Gewane Controlled Hunting Area to the east and north, historically. The boundary, name and the size of the controlled hunting areas have changed and there is no recent map. Figure 1.4 shows the AWR and the surrounding protected areas before the changes in the controlled hunting areas.

The AWR was established as a buffer zone for Awash National Park to the northeast together with Awash West Wildlife Reserve to the west and north (Schloeder and Jacobs 1993). The purpose of these wildlife reserves was to “conserve, manage and propagate the wildlife within them, and where licensed hunting is prohibited, but other forms of controlled land use such as grazing and cattle ranching would not be excluded” (Negarit Gazeta 1972). The reserves were selected with the idea that certain parts of them might serve as corridors between the park and the surrounding plains so that through migration, the wildlife population of Awash National Park would be protected (Schloeder and Jacobs 1993). However, because of the expansion of local towns and villages, shrub encroachment, livestock grazing, and human interference, the original purpose of these border areas is becoming lost.

**Flora and Fauna**

Thirty-one species of mammals have been observed at AWR and the surrounding areas. A species list is provided in Appendix A, 1.1. The most common large herbivores in the AWR have been previously mentioned.

About 70 plant species have also been identified in the study area during this and previous studies (Appendix A, 1.2). *Chrysopogon plumulosus* and *Sporobulus iocladus*
comprise a relatively high percentage of herbaceous vegetation on the plains. The southern, northern, and western edges of the reserve are bush-grasslands or shrublands, with *Acacia senegal* being the dominant species. In some parts of the grassland, *P. juliflora* is becoming the dominant woody species, as will be shown.

**Climate**

Meteorological data (rainfall, daily temperature, and relative humidity) were obtained for 1970-2005 from the meteorological station nearest to AWR at the Melka Werer Agricultural Research Center (WARC), which is administered under the Ethiopian Agricultural Research Organization (EARO). Melka Werer is located at about 8 km from the main tarmac road adjacent to the Allideghi Plain (Figure 1.1).

The annual rainfall ranges from 336 to 818 mm. The rainfall pattern is bimodal with two distinct seasons (Figure 1.7). The short rains occur during March and April, whereas the long rains occur during July and August (Figure 1.5a, b). According to Gemechu (1977), this semi-arid zone in general receives an annual rainfall from 400 to 700 mm.

The mean monthly temperature ranges from 24 to 30°C (Figure 1.6). The coolest temperatures prevail from October to January while the warmest temperatures prevail during May and June. The maximum and minimum temperatures range from 39.9°C in June to 15.5°C in January and from 35.3°C in March to 9.6°C in December, respectively.

Seasonality of the weather is also illustrated by climate diagram that summarize average temperature and precipitation (Figure 1.7). When the precipitation curve
undercuts the temperature curve, the area in between indicates dry season. When the precipitation curve exceeds the temperature curve, the area indicates the rainy (moist) season. Generally, based on 35 years of meteorological data, this confirms that there are two distinct rainy seasons in the area.

**Soil**

Recently, WARC conducted a soil survey on the Allideghi plain (WARC 2003-4). The results indicate that there are two major soil types according to FAO/UNESCO classification: Vertic Cambisols and Calcic Cambisol. The chemical analysis showed that the pH of the soil is alkaline and ranges from 8.1 to 9.1. The organic matter (OM) content is low and ranges from 0.5 - 1.9% (WARC 2003).

**References**


Negarit Gazeta. 1944. A proclamation to make provision for the preservation of game. No. 61 of 1944, order no. 9, May 29, 1944.


perspective on biodiversity, IUCN- The World Conservation Union and the International Academy of the Environment, pp. 287-289.


mesquite (*Prosopis juliflora*) in a highly alkaline soil. - Field Crops Res. 26: 45-55.


Figure 1.1. Map showing the location of the study area.
Figure 1.2. Distribution of Grevy’s Zebra. (Source: Kingdon, 1979)
Figure 1.3. Recorded distribution of Grevy’s Zebra in north-east Africa (Source: Bauer et al. 1994).
Figure 1.4. Location of Allideghi Wildlife Reserve and the surrounding conservation areas.
Figure 1.5 (a, b). Mean monthly rainfall (mm) at Melka Werer, Ethiopia, 1970 to 2005. Source: WARC Meteorology Center (Unpublished data).
Figure 1.6. Average monthly maximum, mean, and minimum temperature at Melka-Werer, Ethiopia, 1971 to 2005. Source: WARC Meteorology Center (Unpublished data).
Figure 1.7. Climate diagram of Melka-Werer, Ethiopia, 1971 to 2005. Source: WARC Meteorology Center (Unpublished data).
CHAPTER 2
TEMPORAL AND SPATIAL PATTERNS OF WILDLIFE
AND LIVESTOCK DISTRIBUTION

Summary

Distribution and patterns of habitat use for large wild herbivores and pastoral livestock at the Allideghi Wildlife Reserve (AWR) were studied in 2005/06. The purpose of this work was to evaluate the sustainability of the reserve to support wildlife in the future. In total, 63 grids of 3.66 x 3.66 km in size were surveyed during one wet and two dry seasons. An average of 72 km were surveyed using 10 parallel transects at 2-minute intervals that were driven throughout the Allideghi Plains. The GPS locations of all wild animals and livestock were recorded and notes were taken concerning grazing intensity and habitat types utilized. The location of permanent settlements and watering sites were also recorded using GPS. Logistic regression analysis was used to determine the seasonal association of wild and domestic animals based on presence/absence criteria for grid cells. The association of wild and domestic animals in relation to permanent and temporary settlements and watering sites was also determined. Focus groups and interviews were conducted with local communities at the Allideghi Plains and interviews were performed with bureau heads and some experts at all levels.

According to local communities, the spatial resource use patterns of wild herbivores was altered after the establishment of permanent pastoral settlements and the concomitant increased livestock access to the Allideghi Plains. The survey results indicated that the spatial resource use patterns of the larger wild herbivores (zebra, oryx,
and gazelle) were negatively associated with the placement of settlements, but not with the locations of foraging livestock. There was an overlap of resource use between wild herbivores and livestock on one fourth to one third of the grids surveyed overall. Grevy’s Zebra, however, were not observed in foraging areas commonly grazed by livestock or in proximity to the permanent settlements. Compared to the other wild animals, zebra were observed, on average, more than 8 km further away from permanent settlements during dry and wet seasons, and a little greater than 4 km after livestock moved off the plains to feed in a nearby cotton plantation. In general, human presence has a negative effect on spatial use of the plains by large wild herbivores. An absence of water on the plains during the dry season forced wild herbivores to travel elsewhere to procure water from hot springs and rivers at night exposing themselves and their offspring to predation from hyenas or lions. Livestock also used these same water sources by day.

The main factor determining the spatial distribution of livestock was the availability of water, with forage as the second most important factor. Except in the case of those permanent settlements having permanent access to water via a borehole, the movement of livestock was influenced by the seasonal and spatial patterns of rainfall. The Allideghi Plain is under high pressure from livestock grazing during dry and wet seasons. The livestock from the five permanent settlements are grazing on the plains 11 months of the year. The intensity of grazing increased during wet seasons because more livestock arrived from other locations and remained for a couple of months until the easily available surface water was gone. The vegetation on the plains can only rest from herbivory for about one month during December/January, which is not a growth period. This small window of time is probably insufficient for rangeland grasses to recover. In
addition, some grassland sites intensively used by livestock have been invaded by *P. juliflora*, and no longer provide high-value herbaceous forages in the understory.

**Introduction**

In the semi-arid and arid biomes worldwide, domestic livestock and large wild herbivores share habitats which provide food, water, cover, and space and offer avenues for disease transmission (Heitschmidt and Stuth 1991, Voeten and Prins 1999, Prins 2000, Young et al. 2005). The relative importance of these factors varies over space and time (Heitschmidt and Stuth 1991). In East Africa, wildlife and pastoral peoples have lived side-by-side for millennia (Lamprey and Reid 2004). Even in the presence of protected areas, large wild animals often occur in adjacent places that are used for the production of livestock (Ottichilo et al. 2000, Lamprey and Reid 2004). Wildlife may occur in the proximity of livestock for several reasons. In some cases, intensive livestock grazing may improve forage condition for wildlife by stimulating nutritious re-growth. In addition, proximity to livestock and herders might help protect wild herbivores from predators (Reid et al. 2003, Lamprey and Reid 2004). Burning of grazing lands by pastoralists can also attract wild ungulates to feed on fresh re-growth (Reid et al. 2003).

On the other hand, there can be considerable diet overlap and resource competition between livestock and wild herbivores in semiarid savannas of Africa (Voeten and Prins 1999, Prins 2000, Mishra et al. 2004, Young et al. 2005). Such resource competition is often largely unbalanced, with species such as cattle having a greater negative effect on wildlife than the reverse. This can result in a decline in the wildlife populations (Prins 2000). Population growth of pastoral and agro-pastoral
people, as well as subsistence cultivation, have also resulted in the decline of wildlife populations and loss of their habitats (Prins et al. 2000).

   Competition and compatibility between livestock and wildlife in Africa has been a point of considerable discussion, with a focus on the implications for wildlife conservation (Heath 2000, Prins et al. 2000, Young et al. 2005). Continued growth of human populations and intensification of land use are jeopardizing the co-existence of wildlife and livestock (Wilson 1989). Growing populations threaten protected areas directly by encroachment of settlements and livestock grazing pressure (Stephens et al. 2001). Thus, if there are any positive effects of pastoralism on wildlife abundance, these can be negated when the density of settlements passes a certain point and land holdings do not permit the free movement of livestock or wildlife (Reid et al. 2003, Lamprey and Reid 2004). Reid et al. (2003) reported that wildlife populations have declined by 70% in the last 20 years in the Mara ecosystem of Kenya because of agricultural expansion, drought, habitat change, and expansion of settlements on the margins of the Mara Reserve. The movements of 75% of wild animal species on the Mara have been restricted primarily due to competition with livestock for forage in neighboring private ranches (Reid et al. 2003). The distribution and abundance of animal species is strongly associated with environmental factors such as vegetation cover, distance to water points, and soil fertility (Buckland and Elston 1993, Khaemba and Stein 2000).

   Allideghi Wildlife Reserve (AWR) provides important wildlife habitat as well as a source of forage for many livestock in the Amibara District of the Afar Regional State. There are five permanent settlements established during the past 30 years at Allideghi Plain and adjacent areas, and all have permanent sources of water. Based on the IUCN
protected-area management categories (IUCN 1994), the AWR falls under category six (i.e., a managed resource protected area). This is defined as “an area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs” (IUCN 1994). This category allows some level of human activity (grazing, collecting wild plant foods, etc).

The AWR is an isolated habitat for Grevy’s Zebra and other important wild animals. Grevy’s Zebra is listed as an endangered species (IUCN 2008), which indicates that this species is facing a very high risk of extinction from its natural environment in the near future. This listing has occurred for the following reasons. First, this species is estimated to have declined by more than 50% during the past 18 years based on direct observation and known and potential levels of exploitation (Klingel 1980, Rowen and Ginsberg 1992, Thouless 1995a, 1995b). In addition, the known total population is estimated to have 750 mature individuals (Moehlman et al. 2008). Second, there is limited evidence of any subsequent population recovery in these regions; rather, research has shown that zebra recruitment rates may continue to be depressed, primarily due to competition with pastoral people and their livestock as well as to long-term effects of overgrazing (Williams 1998). Williams (2002) indicated that the decline in zebra numbers is continuing, but recent surveys show that numbers may be starting to stabilize and recover (Moehlman et al. 2008). The major threats for this species are habitat loss due to human-induced factors such as grazing, expansion of settlements, encroachment by invasive species, and poaching (Moehlman et al. 2008).
Although the AWR provides important services for the pastoral communities living in the area, there has been little or no effort by government to promote conservation via improved resource use and management (A. Kebede, personal observation). In the past, there has been little recognition or understanding concerning the relationships of local communities to biodiversity (Kothari 1994). The greatest challenge of wildlife managers at the present time is to win the support of people living in and around protected areas (Lamprey 1990, Decker and Chase 1997). Since the 1980s, participation of local communities in the planning and management of natural resources is widely considered as an important means of sustaining protected areas (De Boer and Baquete 1998, Nishizaki 2005). In Ethiopia, the consequences of excluding local communities in planning and decision-making processes of protected areas were clearly evident during a period of change in the federal government in 1991. During the period when rural security was lax, local communities disrupted the integrity of protected areas and management systems by slaughtering wildlife, expanding settlements, and bringing in livestock to harvest forage (Stephens et al. 2001). Local communities are now the focal point of conservation thinking (Nishizaki 2005).

Thus, it is important to assess the relations between major wildlife species and pastoral livestock in the AWR. The extent that wildlife and livestock overlap in their habitat use in the AWR is unclear. The issues of local people attitudes towards wildlife conservation need to be examined. Data on the spatial and temporal patterns of habitat use will provide information on how the Grevy’s Zebra and other larger wild herbivores are utilizing the available resources in areas where there is potential competition and
pressure from livestock. The seasonal patterns of livestock and wild herbivore movement will tell us how season affects the expansion and contraction of resource use.

Objectives, Hypotheses, and Predictions

Objective

Determine the spatial and temporal patterns of habitat use by livestock and large wild herbivores.

Hypotheses and Predictions

H1: Resource-use patterns of livestock are influenced by proximity to settlements and water, especially during dry seasons.

P1.1: Site utilization by livestock increases as distance to settlements or water decreases.

P1.2: Site utilization by livestock expands during wet seasons and contracts during dry seasons.

H2: Resource-use patterns of larger wild herbivores are influenced by the proximity of settlements, and patterns of livestock resource use.

P2.1: Site utilization by larger wild herbivores is negatively associated with the placement of settlements and resource-use patterns of livestock.
Description of the Study Area

The general description of AWR is given in Chapter 1. It is a semi-arid system with bimodal rainfall patterns. An important part of AWR is the large grassland area called the Allideghi Plain, which is the focus of this chapter. It covers about 632 km², which is within the boundary of the reserve. It is an important habitat for many wild animals and a good source of forage for pastoralists, who keep large herds of livestock for milk production and wealth accumulation. In reserve systems such as AWR, licensed hunting is prohibited but other forms of controlled land use such as grazing and cattle ranching by local communities are legally allowed (Negarit Gazeta 1972).

The Allideghi Plain is a habitat for larger herbivores such as Grevy’s Zebra, oryx, Soemmering's gazelle, gerenuk, warthog, and ostrich. It is dominated by grass species such as Chrysopogon plumulosus, Sporobulus ioclados and Cenchrus ciliaris and Acacia species on the edges along the asphalt highway and in the mountains to the East. Recently, P. juliflora has been introduced to the plain and occupies some parts of the grassland (Chapter 4).

Materials and Methods

Spatial and Temporal Patterns of Wildlife and Livestock

The spatial pattern of livestock and larger wild herbivores was determined by driving 10 parallel transects separated by a distance of 3.66 km (2’ or 2 minutes) on a seasonal basis. The length of transects was determined based on the accessibility and the physical security of the area. Areas near Awash Arba town were not surveyed as it is a
military zone and areas near the mountains to the East were not surveyed because of on-going tribal conflicts between the Issa and the Afar (Figure 2.1).

The driving was conducted during March (short wet season), December (short dry season), and June (long dry season). It was not possible to conduct the survey during the height of the long wet season (July and August) because muddy, water-logged soils made it impossible to drive on the plains. The location of each sighting of individual animals or groups was recorded using a Global Positioning System (GPS). For each sighting, the type of animals and numbers were determined. Notes were also taken to identify habitat type, the intensity of grazing (Chapter 4 and 5), and the dominant species of vegetation. The location of all permanent and temporary pastoral settlements and watering sites (natural and man-made) was also determined using GPS.

The transects divided the study area into 2’ x 2’ (3660 m x 3660 m) geo-referenced grid cells. Field observations for each cell were plotted on the grid map by season. For each cell the presence/absence of livestock and wild animals was mapped seasonally. The resulting habitat use maps were integrated with distributions of vegetation, settlements, and watering sites using a Geographic Information System (GIS).

Logistic regression (Harrell 2001; Eqn. 2.1) was used to determine the degree of association for spatial and temporal habitat use of livestock and the major wild herbivores based on presence/absence in each grid cell. This model was used to predict the probability of the occurrence of wild herbivores (dependent variables) in a grid cell as a function of distance to settlements, water and distance to livestock (independent variables or predictors) during the three seasons (Zar 1999). A similar approach was also taken for the occurrence of livestock in a grid cell. Presence of animals in a grid cell was coded as
one and absence as zero. The distance of the animal from the independent variables was measured as 0, 1, 2, etc., based on the number of grid cell/cells in between. The temporal and spatial pattern of livestock and wild animals was also related to season of the year and major vegetation types.

The binary logistic regression model is stated in terms of the probability that \( Y = 1 \) given \( X \), the value of the predictors as follows (Harrell 2001):

\[
\text{Prob}\{Y = 1 / X\} = \left[1 + \exp(-X\beta)\right]^{-1}
\]

\textit{Eqn. 2.1}

\( Y \) is the response (dependent) variable,

\( X = X_1, X_2, \ldots X_p \) denote the list of predictors (independent variables),

\( \beta = \beta_1, \beta_2, \ldots \beta_p \) denote the list of regression coefficients (parameters) corresponding to \( X_1, X_2, \ldots, X_p \).

\textit{Focus Group Discussion and Interview}

It is important to understand the relationships between local people and natural resources in designing effective management strategies (Sayre 2004, Tessema et al. in press). According to Sayre (2004) qualitative methods are necessary to understand the social, historical, political, and economic factors affecting use of natural resources. Qualitative methods are normally important to describe the attitudes, knowledge, and behaviors of people (Margoluis and Salafsky 1998).

Questions for key informant interview and focus group discussions (Appendix A, 2.1) were designed following the approach and examples by Margoluis and Salafsky (1998). A translator was used to converse in the local language called \textit{Afar-aff}. Two focus
group discussions were conducted with the permanent users of the Allideghi Plain to
determine their attitudes concerning habitat and wildlife conservation and to what extent
the grassland could be sustainably used by livestock and wildlife. Interviews were also
conducted with the respective bureau heads and experts at local (wereda or district),
regional, and federal levels with an emphasis on any future plans for the management of
the AWR.

Results

Synthesized results are provided in this section. See Appendix B for detailed
statistical analyses.

Availability of Water and Forage

The Allideghi Plain was divided into 93 grid cells. Out of this, 63 grid cells were
surveyed using the 10 transects from east to west and west to east (Figure 2.1a). The
unsurveyed areas to the north and northeast included conflict areas, military zones, or
simply inaccessible sites. Overall, 16% of the surveyed grid cells were categorized as
very heavily grazed grasslands (using a visual assessment) at or near settlements (see
Chapter 3). The remaining cells were categorized as heavily grazed (29%), moderately
grazed (16%), or slightly grazed (25%) grasslands as well as heavily to moderately
grazed shrublands (14%). This may not indicate the exact area for each intensity of
grazing categories and/or habitat types because the grid cells are large.

There are four permanent settlements on the Allideghi Plains which have artificial
watering points, namely permanent sources of water (boreholes) for people and livestock.
There is another borehole at a nearby village called Berta camp just outside the AWR
(Figure 2.1b) for a total of five concentrated areas of human and livestock influence. The boreholes are especially important sources of water for livestock and people during dry periods when no natural sources of drinking water are available in the AWR. The wild herbivores do not have access to water from boreholes.

The Awash River is about 2.5 km (in a straight line) from the boundary of the Allideghi Plain. The other two major sources of natural, permanent water are at the Big Bilen (Kede Bilen) and Small Bilen (Undo Bilen) hot springs, which are about 6.5 and 6.0 km (in a straight line) from the nearest side of boundary of the Allideghi Plain, respectively (Figure 2.1b). These are the natural watering sites that can be accessed by wild animals and livestock.

Overall, while it might appear that wildlife should have easy access to these few natural sources of water, it was apparent (A. Kebede, personal observations) that the interference from people and livestock at these sites is pervasive. No large wild herbivores were observed drinking from the hot springs during daylight hours, for example, either during this survey or in previous work conducted by EWCO staff. However, hoof prints at the springs in the early mornings suggest drinking by wildlife is nocturnal (A. Kebede, personal observation). Distance to the Awash River seems very near from the southwestern part of the plain. However, most of the wild animals do not usually graze in the southwestern part of the plain where there is substantial human activity.

In addition to the hot springs and the river, there are three ephemeral ponds that collect rain water on the Allideghi Plain during the wet season, but all are in close proximity (within 2.5 km) to the settlements. In addition, there are small, ephemeral
streams that originate from the eastern edge of the Allideghi Plain. They are fed by rain water that has accumulated along the escarpment to the east (Figure 2.1c). As with the ponds, water from the streams is only available during the long rainy season.

Spatial and Temporal Patterns of Wildlife and Livestock

Three seasonal livestock resource use patterns were identified at Allideghi Plain. During the dry season (in months except March, April, July, August, and part of September), when the main source of water at Allideghi Plain was limited to the boreholes, the only livestock to use the plain are from the four settlements and the village at Berta camp (Figure 2.2b). The general pattern was for the livestock to forage by day and return to the settlements at night. They feed at a maximum distance of about 11 km from their home settlements at this time, as they are limited by the distance they can cover in relation to their need for daily watering. Livestock drink water when they return to the settlements in the evening.

During the wet season (March, April, July, August, part of September) this general pattern changes. The livestock and many of the people at the settlements temporarily move to the southeastern part of the plain to exploit the abundant forage and make use of water from the ephemeral streams. The people and livestock occupy temporary, satellite settlements at this time in order for the people to maintain ready access to the milk supply each evening and to protect the livestock from possible attack by the Issa. The main settlements with the boreholes are thus mostly free of livestock at this time and are occupied by only a few elderly pastoralists, their caretakers, and a few calves which could not travel long distances (A. Kebede, personal observation). In addition to this
internal movement of people and livestock, livestock and herders from other locations in the Amibara District also temporarily migrate to the southeastern part of the plain during the wet season (Figure 2.2d). Animals were kept in these locations in temporary corrals until the ephemeral water sources dried.

The third pattern was during the month of December, which is in the dry season. Most of the permanent resident livestock of the Allideghi Plain and the surrounding areas migrate to nearby cotton plantations for about a month to feed on crop residues after cotton harvest with very few livestock foraging on the plain (Figure 2.3.b).

Dry Season. It was predicted that settlements and foraging livestock would have negative effects on the occurrence of the larger wild herbivores. As predicted, site utilization by larger herbivores such as zebra, oryx, gazelle, and ostrich was negatively affected by placement of permanent settlements during the dry season (Table 2.1). The logistic regression model revealed that the relationship was significant (p<0.05).

Contrary to the prediction, however, considered overall, the wild herbivores tended to be positively associated with foraging livestock in most cases at this time. Variation occurred for individual species, however. There was no significant association between livestock and zebra or oryx compared to that of gazelle and ostrich. Both wild and domestic animals were observed in 29% of the surveyed grid cells during the dry season (Figure 2.4.a).

Grevy’s Zebra showed limited distribution during the dry season concentrating in the northern part of the plain compared with the other larger herbivores (Figure 2.5). There are no settlements or intensive use by livestock in these areas. This site also is in relatively close proximity with the hot springs. Oryx has relatively wider distribution and
they are also observed further away from settlements in the northern or southeastern part of the plain (Figure 2.5.b). Gazelle and ostrich have wider distribution from north to south (Figure 2.5.c,d). The northern part of the plain can usually be considered as a no-man’s land situated between the conflicting Afar and Issae tribes. Both Issa and Afar don't usually take their livestock to these sites. The area is dominated with lightly grazed *C. plumulosus* and *C. ciliaris*.

In December, when most of the livestock from the permanent settlements migrated to the cotton fields to forage, distance to permanent settlements was not very important in influencing the pattern of occurrence of wild herbivores, with the exception of oryx (Table 2.2). At this time, most wildlife came relatively closer to settlements compared to when livestock were foraging in the area. There were only three observations of livestock (two small groups of calves and one small group of camels) during this time on the Allideghi Plains, and in each case the wild herbivores foraged in close proximity with livestock. It might be important to note that there were no herders with these livestock.

In December, some zebras were observed a little further south but still with close proximity to the hot springs compared to the Awash River (Figure 2.6.a.). Oryx also have limited their distribution to the north and east where there is no settlement (Figure 2.6.b) as in June. Gazelle and ostrich have extended a little their distribution in the absence of the majority of livestock in the area (Figure 2.6.c,d). The relationship of zebra, gazelle and ostrich with that of settlements was not significant. However, oryx were still observed further away from settlements (Table 2.2).
Wet Season. As mentioned above, many livestock migrate to the Allideghi Plain temporarily twice a year during the short and long rainy seasons when surface water is temporarily available. The survey for the wet season was conducted only during the short rainy period (March). The logistic regression indicated that wild animals in general were negatively associated with the permanent settlements (p<0.05). However, the same association was not significant for zebra, gazelle, and ostrich individually (Table 2.3). The logistic regression also revealed that, despite a dramatic increase in the numbers of livestock utilizing the Allideghi Plain during the wet season, most of the wild herbivores were still observed grazing in positive association with livestock (Table 2.3; p<0.05). This again was contrary to the prediction of a negative association. However, this association was not significant for zebra.

During the wet season all the livestock from the permanent settlement also moved to temporary settlements in the southeastern part of the plain. As the temporary settlements are occupied in the wet season, it was expected that there would be a negative association of wild animals with temporary settlements. However, wild animals in general showed no significant association with the temporary settlements, although the pattern was positive for oryx and gazelle and negative for zebra and ostrich (Table 2.3; p>0.05). The availability of green vegetation in the southeastern portion of the plain (supplied with water from the ephemeral streams) appeared to attract the wild animals. In terms of resource-use overlap between wild animals and livestock, there was an overlap of resource use in 24% of the surveyed grid cells (Figure 2.4b).

Even though wild herbivores were observed in closer proximity to temporary watering sites, the logistic regression indicated that the association was not significant
(p>0.05). Even the livestock were further from temporary watering sites as they were using the ephemeral streams (Figure 2.1c). These temporary watering sites, which hold water for a certain period of time after the rain stops, might be important after all the other ephemeral water sites have dried up.

With the increased availability of surface water during wet season, some Grevy’s Zebra extended their spatial distribution to the south, but this was further from the active temporary settlements when compared with distributions of the other wild herbivores (Figure 2.7). Some oryx, gazelle and ostrich were observed within a 3.6 km distance from the temporary settlements.

In general for both seasons, as predicted, site utilization by livestock increased as the distance to settlements and water sources decreased. In addition, the size of areas used by livestock expanded during the wet season and contracted during the dry season as predicted, with the exception of the temporary migration to the cotton fields in December.

As shown in Figure 2.8, the Allideghi Plains are dominated by grassland with some lightly wooded grassland and shrubland. About 5% of the grassland is now occupied by *P. juliflora*. Wild grazers such as zebra, oryx, and gazelle were typically observed on the grassland and lightly wooded grassland. The gerenuks were all observed near the shrubland. It is important to mention that very few gazelles and warthogs were observed on heavily grazed grassland with scattered *P. juliflora*.

Census surveys indicated that the population of Grevy’s Zebra observed during the three periods numbered a little less than 50 (Table 2.4). Their number decreased by few individuals during the dry periods. Most of the oryx and some of the gazelles and
ostriches which were observed in March and December were not observed in the driest month of the year, June. As mentioned earlier, some part of the northern (grassland) and north eastern (open bushland) part of the reserve (Figure 2.8) was not surveyed intensively due to insecurity. In June, some of the animals might be grazing in the open bushland while benefiting from the shade from associated woody plants. The census data also showed that the number of livestock grazing on the Allidegh plain during the short rainy season doubled compared to that of the dry season in June (Table 2.4). The number might be higher during the long rainy season in July and August when the amount of rainfall is higher to support more animals and promote the growth of new sprouts throughout the area.

*Attitudes of Local Communities Towards Wildlife Management*

General Background Information. The people at the Allidegh settlement have lived in the area for more than 30 years. This was facilitated by the establishment of boreholes for the livestock holding ground. Other settlements at Udula-Isae and elsewhere began about 9 years ago. They also are served by boreholes. The advent of boreholes has allowed the transition from the temporary seasonal grazing use that was traditional to the heavier permanent use observed today.

The main reason pastoralists prefer the Allideghi Plains for permanent settlement is because it has the most superior forage resources in Amibara District. All the residents of the permanent settlements are primarily livestock herders. Their main source of income is livestock, whether via food production or sales. Some of the herders have small plots of land at the cotton plantation since 1994. Very few people receive wages from
local employers such as a livestock exporting firm (ELFORA), government cotton plantations, or other organizations

When asked to describe their priority problems at AWR, the focus group discussants mentioned: (1) lack of health care for people and livestock; (2) lack of transportation, (3) occasional irregularity in water access (notably times when a water pump breaks down at a borehole), and (4) invasion of *P. juliflora*. Some of the residents noted that they have to travel longer distances from home to locate adequate forage for their livestock because of *P. juliflora* encroachment. Despite these challenges, the discussants concluded that they want to live in the area indefinitely as long as permanent water is maintained.

The permanent settlers of Allideghi Plain use the site for about 11 months per year, except for the period in December/January when they temporarily use the cotton fields after harvest. Camels usually graze in other areas crossing the Awash River and Bilen areas. However, the Allideghi Plain serves as a temporary grazing site for many livestock throughout the district during the rainy periods.

Attitudes of People Towards the Sustainability of Allideghi Plain. The human and livestock population living at the Allideghi plain is increasing as the forage supplies at the Melka Werer area are decreasing. Group respondents said that they have no other option to move elsewhere because other sites are already used for crop agriculture, occupied by *P. juliflora*, or are no-man’s lands near territory held by the Issa. The local government has tried to resolve the conflict between Issa and Afar by establishing a peace committee that includes members from both tribes and government officials. In the past, promotion of peace allowed pastoralists like the Afar to travel throughout the
district with few restrictions. However, peace has been short-lived as, according to the Afar informants, the Issa began to break mutual agreements.

In general, the group discussants rated the Allideghi Plain high in terms of forage resources compared with other areas in the district. However, they believed that its grazing potential was decreasing over the past 10 years as more and more livestock are using it. In addition, the people are concerned that forage sources are gradually being lost as a result of *P. juliflora* encroachment. The discussants mentioned that the increasing grazing pressure coupled with *P. juliflora* encroachment and periodic droughts (most recently in 2004) suggests that the future will be very difficult in terms of sustained forage availability on the AWR for both wild animals and livestock. They have now started to clear the sites encroached with *P. juliflora* and restore herbaceous productivity (see Chapter 4).

The respondents agree that keeping fewer, but healthier livestock with an enhanced market value is important under conditions of steadily reducing forage availability. It remains true, however, that cultural forces persist that promote maximization of livestock numbers, and this is a difficult attitude to change. This challenge has been observed elsewhere (Coppock 1994).

Attitudes of People Towards Wildlife Management. In the past, the local people recalled that major wild herbivores at AWR such as zebra, oryx, ostrich, and gazelle used to be seen foraging in close proximity to livestock. This is no longer the case, and it is especially true for zebra that keep a wide distance from pastoralists at all times. In addition, other species besides zebra tend to avoid being too close to livestock, especially if a herder is present. Why the change? Respondents say that the situation today differs
from the past because many herders now accompanying livestock carry guns to protect themselves and their livestock from attack by the neighboring Issa. (For example, 10 Afar and seven Issa were killed in October 2004.) Another factor is the larger number of people and livestock using the AWR since the 1970s. All of these factors have forced wildlife and livestock into a progressively smaller resource area. According to the Afar respondents, the potential for competition among livestock and wildlife is now potentially intense.

The older discussants mentioned that they are protecting the wild animals “as they are creatures of God.” They are obliged by their ancestors to protect them due to the belief that if the wild animals disappear from the AWR, so will their livestock. They have also been told by their elders that during very serious droughts when all livestock die, their ancestors survived by feeding on the wild animals. The younger pastoralists that were interviewed do not appear to have this cultural tie with the wild animals (Kebede, personal observation). In general, these people mentioned that they don't get any direct benefits from wildlife at Allideghi, except for per diems that a few receive when wildlife scientists visit the area. When asked about the future possibility of local tourism, the respondents said they would be happy to be involved in the process and get a direct benefit from the wildlife. Such an arrangement could lead the Afar to help protect the wildlife from depredation by the Issa. It is less clear about how tourism could affect the willingness of the Afar to protect carnivores such as lions, hyenas, and jackals that also attack livestock and people.

According to the discussants, there has been a noticeable decrease in the population size of zebra and other wild herbivores during the past two decades at AWR.
They associated these declines with the increase in people and livestock. According to the people, the cues used by some wild animals to avoid people and livestock are subtle. For example, they believe that zebra avoid grasses that have been touched by people or livestock. But oryx and gazelle sometimes feed in areas previously grazed by livestock. The number of wild species is also reportedly decreasing. The African Wild Ass (*Equus africanus*), Swayne's Hartebeest (*Alcelaphus buselaphus swaynei*), and Defassa Water Buck (*Kobus defassa*) once present in the area are now locally extinct. The main cause the discussants mentioned for the decline and disappearance of wild animals is interference from people, livestock, and competition for forage during droughts.

The discussants admitted that some people have killed zebra in the past when there is illness that causes people to become thin. Zebra meat is regarded to have medicinal value that allows people who consume it to gain weight quickly. However, the respondents said that they no longer poach zebra. They said they now have access to modern medicine in the towns and their behavior has changed. In addition, the people are now more aware of passages in the *Holy Kuran* that Muslims are not allowed to eat meat of animals that do not regurgitate. Some still believe that the fat of ostriches is important for people with tuberculosis, and that ostrich eggs and meat are important cures for asthma. However, people who have camels don't kill ostriches since they believe that their camels will die if they do so. The respondents noted that gazelles and oryx are useful for their meat only, and offer no particular health benefits. The people also mentioned that they do not hunt the Gerenuk, also for religious reasons.

Current and Future Plan of the Government to Manage AWR. According to results from interviews with local and regional government officials, there appear to be
no measures under consideration that are specifically targeted to better manage AWR and protect the remaining wildlife such as Grevy’s Zebra. The main operational focus is on agricultural extension programs, sport hunting of non-endangered species in controlled hunting areas (often conducted by professional hunters with foreign tourist hunters), and awareness-creation workshops about wildlife conservation to local communities in collaboration with the federal government. There is no plan to manage AWR in the future even though officials seem to be aware of the importance of AWR for endangered wildlife.

The district officials reported on a recent proposal prepared for local development activities to improve water access, animal fattening programs, and road construction that could benefit local communities. FARM Africa helped them to get the training and experience from the Borana people. One aspect is for local communities to share 30% of the income from tourist hunters to better gain their support for local wildlife conservation. The regional bureau admitted that the remaining money is not used for wildlife conservation.

A regional conservation strategy was approved about four years ago by the Afar Regional State. As of this writing, however, no aspects of the plan have been implemented (Mohammed Mahmud, Head of Environment Protection, Afar Regional State, pers com). The regional government does have an interest to manage AWR and the neighboring Yangudi Rassa National Park (YRNP). However, the first priority is to solve the conflict between the Issa and the Afar. Only when this conflict is solved can such conservation activities proceed.
At the federal level, Grevy’s Zebra and other endangered species in Ethiopia are protected from hunting. Studies are now being carried out on endangered species such as Grevy’s Zebra at Allideghi and Chew Bahir, the Bale Mountains grivet monkey in Bale Mountains National Park, and the Degodi Lark on the Borana Plateau. These reports should provide key management recommendations for these species. The federal government has also a plan to upgrade the AWR and other reserves to national park status (Tadesse Hailu, former Department Head, EWCD).

Discussion

After the introduction of irrigation schemes in the Middle Awash Valley starting in 1969, when commercial farms were established in the dry-season grazing areas of Melka Werer and Melka Sedi, the grazing patterns of the Afar pastoralists in Amibara District changed dramatically (Getachew 2001). Previously, during the rainy seasons, the Afar livestock moved to the Allideghi Plain temporarily, and during dry periods they moved to dry-season grazing along the Awash River. Currently, however, this pattern has changed in that many permanent settlements have been established on the Allideghi Plain during the past three decades. As indicated in this study, livestock in the permanent settlements, where there is now a reliable supply of water from boreholes, forage on the AWR 11 months per year. A study by Abule et al. (2005) indicated that the condition of rangelands in the Middle Awash is declining mainly due to overgrazing, droughts, and an increase in human population under communal grazing regimes.

According to the Central Statistical Authority survey in 1994, the total people living in Amibara district was 40,175 with national estimate average growth rates of
2.23% in rural areas and 4.11% in urban areas (Ame 2004). Of which, about 48% are settled in urban areas and the remaining 52% in rural areas. OXFAM Ethiopia (2002) estimated about 19,655 cattle living in Amibara district. The pastoralist in Amibara district spends the rainy season on the Allideghi (Ame 2004) and as confirmed in this study. Even though there were about 9,345 cattle observed at Allideghi Plain during the short rainy season, this number may increase during the long rainy season.

At Allideghi where there is forage, water remains a limiting factor for livestock use of the area. Where water problems have been solved, forage is the limiting factor. The hierarchy of needs is dynamic because they vary as a function of changing habitat relative to demands of herbivores (Krebs and Davies 1984, Mangel and Clark 1986). The current resource use patterns are guided by seasonal rainfall as well as establishment of permanent settlements and artificial watering sources.

This study showed that site utilization by livestock increases as the distance to settlements and water sources decreases, and it expands during the wet season and contracts during the dry season. In addition, when the forage resource gets scarce around villages during the dry season (see chapter three), livestock travel longer distances and change the pattern of drinking water from every day to every-other-day. Pastoral livestock can adjust their drinking needs to once every 1 to 3 days depending on ambient conditions (Coppock et al. 1988). Bailey et al. (1996) mentioned that both distance to water as well as quality and quantity of forage affect grazing distribution patterns of large herbivores. Especially in semi-arid savannas, irregular water availability affects the possibilities of drinking and the quantity and quality of food for large herbivores (McNaughton and Georgiadis 1986, Skarpe and Bergstorm 1999).
During the dry season, drinking water is not generally available for wild herbivores within the Allideghi Plain. Thus, they are forced to travel away from their habitat to search for water. Even though there are permanent natural watering sites less than 10 km away, interference by people and livestock limit access to these locations by wildlife and force wild animals to use water sites at night. The same pattern might be possible while accessing the ephemeral rivers during the wet season within the plain since it is mostly used by domestic animals during the day. A study in northern Kenya showed that livestock and human activities related to water points negatively affect the distribution of wild animals (de Leeuw et al. 2001). However, lactating females of wild equids in arid habitats such as Grevy’s Zebra need to drink at least once a day (Moehlman 2005), which will force them to travel long distances to the water sites in the evening, leaving the foals behind. The same pattern was observed in the northern Kenyan population of Grevy’s Zebra (Williams 1998). Such limited access to water and possible competition for forage impacts the survival rate of foals and population recruitment (Moehlman 2005).

This study showed that the larger wild herbivores were more often observed further from permanent settlements and temporary settlements occupied by people and livestock. Similar patterns have been observed in other parts of Africa (Happold 1995, Bergstrom and Skarpe 1999). Intensive livestock grazing at and near villages often results in considerable change of wildlife habitats (Parris and Child 1973, Skarpe 1986). However, when there were few people at the permanent settlements during the wet season, the presence of the permanent settlements per se did not impact resource use patterns of most wild herbivores. This suggests that the resource use pattern of most wild
herbivores is negatively affected by the human interference, but not by the presence of livestock. Thus, direct disturbance such as hunting and heavy grazing by livestock around the villages and shortage of preferred forage might deter the wild herbivores from grazing near villages (Parris and Child, 1973, Bergstrom and Skarpe 1999).

During both wet and dry seasons, many people accompany livestock while grazing. Here, it is important to explain that most of the herders with guns go further distances in advance of livestock movement to check the risk from the Issa. People with guns also form a rear guard for livestock when animals return to the settlement. Only a few herders stay near the livestock while they are foraging. These results showed that wild herbivores consistently avoided humans. This result is in agreement with what the people mentioned about the previous pattern of wild herbivores: they were grazing near or together with livestock when there were few people living on the plain and people with guns were not accompanying the livestock. Similarly, distribution of elk and mule deer and habitat use by elk has changed when cattle were introduced to the range in Arizona (Wallace and Krausman 1987). Thus, as more and more areas are used by livestock, the resource use overlap between livestock and wild herbivores would be increasingly evident. When livestock and feral horses share the same vegetation type, direct competition for forage existed (Miller 1983). In both seasons, wild herbivores were grazing closer to livestock except in the case of the zebra. The people also mentioned that the zebra are more reclusive than the others. In my observation, usually small groups of wild herbivores (gazelle, warthog) graze in relatively closer distances to livestock, but not together. There might be a difficulty to detect the impact of livestock on the spatial
distribution of wild herbivores overall because of the coarse resolution of the data collection due to the large size of the grid cells.

The conflict between Issa and Afar has created some inter-tribal buffer areas where livestock do not usually travel. Most of the wild herbivores, including the zebra and Oryx, were observed in this buffer zone, which is lightly or ungrazed grassland in most cases. Large herds of gazelle usually inhabit the part of the grassland dominated by annuals in the lightly grazed zone. Other studies have indicated that significantly fewer elk and mule deer were seen on pastures grazed by cattle than on pastures not grazed by cattle (Wallace and Krausman 1987). The zebra can utilize tall and less nutritious grass (Khaemba and Stein 2000) while cattle require higher quality diets than equids (Krysl et al. 1984).

In semi-arid areas of Africa, there is competition and violent conflict over natural resources among users (Coppock 1994, Abule et al. 2005). The other issue affecting the spatial resource use is the conflict between the Afar and Issa as the livelihoods of both pastoralist and agro-pastoralist tribes depend on key resources such as forage and water. As these resources diminish over time, the competition for resources will intensify and cause more and more conflicts to occur (Gebre Michael et al. 2005). Cattle rustling is also another important causes of the conflict between these tribes. Traditionally, the family of a young man would need to pay a dowry if he wants to get married to someone other than his cousins (*absuma*). If they don't have enough cattle for such purpose, some people steal from other tribes. Such conflicts might limit the success of future wildlife conservation programs in the area (Jacobs and Schloeder 2001).
Conclusions

The establishment of the Amibara Melka-Saddi irrigation farms in dry-season grazing areas, coupled with the provision of artificial water sources, is the major source of changes in resource use patterns of livestock at Allideghi Plain. This pattern increases human and livestock populations on the Allideghi Plain. Humans and livestock have impacted resource use patterns of wild animals. As forage resources are scarce in the district, it is impossible to reverse this pattern to its original status. The invasion of *P. juliflora* may aggravate the current trend of human and livestock influence at the Allideghi Plain (see Chapters 4 and 5).

Currently, both the federal and regional governments are not physically involved in the management of the AWR. There is no wildlife manger who can regulate human activities and no infrastructure to help future management activities in the AWR. Thus, the regional government is advised to step-up its efforts of wildlife management from awareness creation and regulating sport hunting to developing an infrastructure and aggressively promoting wildlife management. This can only succeed by involving the local communities in the process.

References


Table 2.1. Effects of distance to permanent settlement and distance to foraging livestock on the occurrence of major wild herbivores during the dry season at Allideghi Plain.

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables</th>
<th>Reg. Cof. (B)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gazelle</td>
<td>Permanent settlement</td>
<td>0.792</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.642</td>
<td>0.002</td>
</tr>
<tr>
<td>Ostrich</td>
<td>Permanent settlement</td>
<td>0.856</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-2.496</td>
<td>0.001</td>
</tr>
<tr>
<td>Oryx</td>
<td>Permanent settlement</td>
<td>1.425</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-0.703</td>
<td>0.193</td>
</tr>
<tr>
<td>Zebra</td>
<td>Permanent settlement</td>
<td>2.303</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-0.815</td>
<td>0.331</td>
</tr>
<tr>
<td>Wildlife (^4)</td>
<td>Permanent settlement</td>
<td>0.894</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-2.152</td>
<td>0.0003</td>
</tr>
<tr>
<td>Livestock</td>
<td>Permanent settlement</td>
<td>-0.796</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Foraging wildlife</td>
<td>-2.105</td>
<td>0.003</td>
</tr>
</tbody>
</table>

1 Presence/absence of wild and domestic animals was collected from a total of 63 grid cells.
2 For the dependent variables, distances were measured using grid cells as '0' if the dependent and independent variables were found in the same grid cell, ‘1’, if they were 1 grid cell apart, and so on, regardless of the number of observations in a grid cell and abundance.
3 Positive values indicated that the chance of observing wild animals or livestock increased as distance to the independent variables increased. The opposite is true for negative values.
4 Includes observations of gazelle, ostrich, oryx, zebra, gerenuk and warthog combined.
Table 2.2. Effects of distance to permanent settlements and distance to foraging livestock on the occurrence of major wild herbivores during the dry season month of December at the Allidegh Plain when most livestock temporarily migrate to cotton plantations.¹

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables²</th>
<th>Reg. Cof. (B) ³</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gazelle</td>
<td>Permanent settlement</td>
<td>0.556</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.202</td>
<td>0.005</td>
</tr>
<tr>
<td>Ostrich</td>
<td>Permanent settlement</td>
<td>0.588</td>
<td>0.069</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.062</td>
<td>0.014</td>
</tr>
<tr>
<td>Oryx</td>
<td>Permanent settlement</td>
<td>1.054</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-0.616</td>
<td>0.103</td>
</tr>
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<td>Zebra</td>
<td>Permanent settlement</td>
<td>0.658</td>
<td>0.267</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.004</td>
<td>0.168</td>
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<tr>
<td>Wildlife⁴</td>
<td>Permanent settlement</td>
<td>0.545</td>
<td>0.062</td>
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<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.156</td>
<td>0.005</td>
</tr>
<tr>
<td>Livestock</td>
<td>Permanent settlement</td>
<td>-1.126</td>
<td>0.161</td>
</tr>
<tr>
<td></td>
<td>Foraging wildlife</td>
<td>-0.426</td>
<td>0.709</td>
</tr>
</tbody>
</table>

¹ Presence/absence of wild and domestic animals was collected from a total of 63 grid cells.
² For the dependent variables, distances were measured using grid cells as '0' if the dependent and independent variables were found in the same grid cell, ‘1’, if they were 1 grid cell apart, and so on, regardless of the number of observations in a grid cell and abundance.
³ Positive values indicated that the chance of observing wild animals or livestock increased as distance to the independent variables increased. The opposite is true for negative values.
⁴ Includes observations of gazelle, ostrich, oryx, zebra, gerenuk and warthog combined.
Table 2.3. Effects of distance to permanent and temporary settlements, distance to foraging livestock, and distance to temporary watering sites on the occurrence of major wild herbivores during the wet season at Allideghi Plain.1

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables2</th>
<th>Reg. Cof. (B)3</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
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<td>Permanent settlement</td>
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<td>0.295</td>
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<td></td>
<td>Foraging livestock</td>
<td>-1.205</td>
<td>0.037</td>
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<tr>
<td></td>
<td>Temporary settlement</td>
<td>-0.188</td>
<td>0.487</td>
</tr>
<tr>
<td></td>
<td>Temporary water</td>
<td>-0.300</td>
<td>0.395</td>
</tr>
<tr>
<td>Ostrich</td>
<td>Permanent settlement</td>
<td>0.808</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td>Foraging livestock</td>
<td>-1.704</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Temporary settlement</td>
<td>0.138</td>
<td>0.592</td>
</tr>
<tr>
<td></td>
<td>Temporary water</td>
<td>-0.186</td>
<td>0.591</td>
</tr>
<tr>
<td>Oryx</td>
<td>Permanent settlement</td>
<td>1.078</td>
<td>0.048</td>
</tr>
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<td></td>
<td>Foraging livestock</td>
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</tr>
<tr>
<td></td>
<td>Temporary settlement</td>
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</tr>
<tr>
<td></td>
<td>Temporary water</td>
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<tr>
<td>Zebra</td>
<td>Permanent settlement</td>
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<td>Foraging livestock</td>
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<td></td>
<td>Temporary settlement</td>
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<td></td>
<td>Temporary water</td>
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<td>Wildlife4</td>
<td>Permanent settlement</td>
<td>1.158</td>
<td>0.021</td>
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<td>Temporary settlement</td>
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<td>Temporary water</td>
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<td>Temporary water</td>
<td>0.212</td>
<td>0.567</td>
</tr>
</tbody>
</table>

1 Presence/absence of wild and domestic animals was collected from a total of 63 grid cells.
2 For the dependent variables, distances were measured using grid cells as ‘0’ if the dependent and independent variables were found in the same grid cell, ‘1’, if they were 1 grid cell apart, and so on, regardless of the number of observations in a grid cell and abundance.
3 Positive values indicated that the chance of observing wild animals or livestock increased as distance to the independent variables increased. The opposite is true for negative values.
4 Includes observations of gazelle, ostrich, oryx, zebra, gerenuk and warthog combined.
Table 2.4. Number of major wild and domestic animals observed at the Allideghi Plain along 10 transects.

<table>
<thead>
<tr>
<th>Month/Species</th>
<th>Grevy’s Zebra</th>
<th>Sommering’s Gazelle</th>
<th>Gerenuk</th>
<th>Ostrich</th>
<th>Warthog</th>
<th>Common Jackal^1</th>
<th>Livestock</th>
<th>Camel</th>
<th>Sheep and goats</th>
<th>Donkey</th>
</tr>
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<tbody>
<tr>
<td>March</td>
<td>48</td>
<td>743</td>
<td>703</td>
<td>11</td>
<td>476</td>
<td>55</td>
<td>13</td>
<td>9345</td>
<td>16</td>
<td>832</td>
</tr>
<tr>
<td>December</td>
<td>45</td>
<td>492</td>
<td>876</td>
<td>47</td>
<td>227</td>
<td>33</td>
<td>3</td>
<td>69</td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>June</td>
<td>43</td>
<td>78</td>
<td>470</td>
<td>11</td>
<td>115</td>
<td>25</td>
<td>8</td>
<td>4818</td>
<td>261</td>
<td>582</td>
</tr>
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</table>
Figure 2.1(a-c). Map showing the Allideghi Plain data units of 3.66 x 3.66 km grid cells. 

a - Surveyed and un-surveyed grid cells, b - Permanent settlements and watering sites, c - Temporary settlements (active during the study) and watering sites.
Figure 2.2 (a-d). Map showing the spatial and temporal resource use pattern of large wild herbivores and livestock on the Allideghi Plain during dry and wet seasons. Presence/absence of wild and domestic animals was collected from a total of 63 grid cells. Wild animals include gazelle, ostrich, oryx, zebra, gerenuk and warthog. a - Presence/absence of wild animals during the dry season, b - Presence/absence of livestock during dry season, c - Presence/absence of wild animals during the wet season, d - Presence/absence of livestock during the wet season.
Figure 2.3 (a-b). Map showing the spatial and temporal resource use pattern of large wild herbivores and livestock on the Allideghi Plain when most livestock migrate temporarily to the cotton fields. Presence/absence of wild and domestic animals was collected from a total of 63 grid cells. Wild animals include gazelle, ostrich, oryx, zebra, gerenuk and warthog. a- Presence/absence of wild animals, b - Presence/absence of domestic livestock.
Figure 2.4 (a-b). Map showing the spatial and temporal resource use overlap of large wild herbivores and livestock on the Allideghi Plain. Presence/absence of wild and domestic animals was collected from a total of 63 grid cells. Wild animals include gazelle, ostrich, oryx, zebra, gerenuk and warthog. a - Overlap of resource use during dry season, b - Overlap of resource use during wet season.
Figure 2.5 (a-d). Map showing the spatial and temporal distribution of four important wildlife species on the Allideghi Plain during dry season. Presence/absence of wild animals was collected from a total of 63 grid cells. a – Grevy’s Zebra, b - Oryx, c - gazelle, d - Ostrich.
Figure 2.6 (a-d). Map showing the spatial and temporal distribution of four important wildlife species on the Allideghi Plain when most livestock migrate temporarily to the cotton fields. Presence/absence of wild animals was collected from a total of 63 grid cells. a – Grevy’s Zebra, b - Oryx, c - gazelle, d - Ostrich.
Figure 2.7 (a-d). Map showing the spatial and temporal distribution of four important wildlife species on the Allideghi Plain during wet season. Presence/absence of the wild animals was collected from a total of 63 grid cells. a – Grevy’s Zebra, b - Oryx, c - gazelle, d - Ostrich.
Figure 2.8. Vegetation classification of the Allideghi Plain.
CHAPTER 3
EFFECTS OF LIVESTOCK GRAZING ON BIOMASS,
UTILIZATION, PRODUCTIVITY, AND SPECIES
RICHNESS OF PERENNIAL GRASSLAND
AT ALLIDEGHI PLAIN, ETHIOPIA

Summary

In Ethiopia, policy allows moderate livestock grazing in wildlife reserves. However, increasing pastoral populations, loss of other grazing lands, and development of artificial water points in and around the Allideghi Wildlife Reserve (AWR) has intensified livestock grazing pressure in recent decades. This has raised concerns about the sustainability of the perennial grassland. The study determined the responses of herbaceous vegetation to a livestock grazing gradient associated with a borehole water source. It was predicted that standing crop biomass, above-ground net primary production (ANPP), and species richness would decrease with increased proximity to the water point. An alternative outcome was that ANPP and species richness would peak at an intermediate level of grazing disturbance. Forage utilization was expected to increase closer to the water point.

Percent herbaceous basal cover was used as a measure of grazing intensity at different distances from the water point. Four levels of grazing intensity (severe, heavy, moderate, and an ungrazed control) were identified. For each level, four 3 x 3 m exclosures and adjacent unprotected sites were established. Standing biomass and species richness were determined using clipping and species counts, respectively from two 50 x
50 cm quadrats randomly selected from each quarter of the exclosures and adjacent sites, both in June (end of the dry season) and October (end of the growing season). In addition, herbaceous composition (in terms of grass and forb functional groups) and utilization of herbaceous vegetation were estimated along the grazing gradient using clipping.

The concentrated impacts of livestock grazing and trampling around the borehole watering site created a sacrifice zone (piosphere) exceeding 28 hectares in size (not circular; refer site selection). Total standing-crop biomass decreased steadily closer to the watering site, with a net reduction of 95% at the end of the dry season to 82% at the end of the wet season. Plant composition also underwent dramatic changes from 94% grass at the control site to over 96% forbs at severely grazed sites. Utilization of grass increased, and that of forbs decreased, with the increase in distance from the watering site in line with respective changes in their availability. However, 74% of the standing biomass was utilized at the intermediate grazing intensity, where grass species started to dominate composition.

Total ANPP of protected plots at severely grazed sites was significantly lower than values at other sites. However, ANPP at heavily and moderately grazed sites was not significantly different from that of the control, indicating that the plant community was able to endure relatively heavy levels of grazing. A similar pattern was observed in terms of species richness: total number of species at severely grazed areas was significantly lower than that of other sites, which were similar to each other. In all cases, the contribution of grasses to species richness was lower compared to that of forbs.
Livestock grazing has severely impacted the plant community in the vicinity of the watering point. At the same time, the herbaceous vegetation demonstrated resilience at heavily and moderately grazed sites. Lack of palatable forage at severely grazed sites, coupled with high utilization at the heavily grazed sites, suggest that the piosphere will continue to expand if the present patterns of livestock use continue.

Introduction

World wide, rangelands are major ecosystems providing multiple ecological, environmental, and economic functions (Lund 2007). An important part of conserving rangelands has been through the establishment of protected areas (Gorkhali 1986). Many protected areas have been developed as wilderness preserves for public recreation without permanent human habitation or extractive use (Kemf 1993). In other cases, wildlife populations occur on “protected” lands which are also being used by pastoralists or ranchers for the production of livestock (Lamprey and Reid 2004, Young et al. 2005). In the past, wildlife has lived side-by-side with pastoral peoples and their livestock for many years (Lamprey and Reid 2004). However, recent increases in human population and changes in land use are jeopardizing the co-existence of wildlife and livestock (Wilson 1989).

In arid and semi-arid areas such as AWR, most large mammals require regular access to drinking water. Lack of sufficient access to drinking water in dry environments has lead to the development of water via boreholes or earthen works where large numbers of livestock can congregate. In such environments, availability of water is a major determinant of livestock distribution (Landsberg and Stol 1996, Mphinyane 2001) as they
are obliged to return to water frequently. Thus, sources of water become foci of
grazing activity and can result in impacted zones termed piospheres (Lange 1969).

One characteristic feature of arid and semi-arid rangeland ecosystems is their
resilience in response to widely fluctuating pressures (Harrington et al. 1984). Some
studies indicate that grazed grasslands of Africa can be remarkably resilient
(McNaughton 1979, Mentis and Tainton 1981, Ellis and Swift 1988). Given light to
moderate herbivory widely distributed over a varied landscape, native plant communities
that have co-evolved with herbivores can thrive (McNaughton 1993, Hobbs 1996). It has
also been reported, however, that increases in grazing pressure in arid and semi-arid
environments can result in loss of perennial grasses while the proportion of forbs and
annual grasses increase along with replacement of palatable by unpalatable species (Kelly
and Walker 1976, van der Maarel and Tityonova 1989, O’Connor and Picket 1992, Fusco

The impact of livestock grazing on species composition and productivity of
rangelands has been a controversial issue (DeAngelis and Huston 1993, Dyer et al. 1993,
McNaughton 1993, Painter and Belsky 1993). There are two extreme views: livestock as
a destructive force (Bock and Bock 1993) and livestock as an important component in the
maintenance of rangeland ecosystems (Milchunas et al. 1998). The hypothesis of
herbivore optimization predicts that intermediate levels of herbivore grazing
(disturbance) result in maximum net primary production and species diversity when
compared with ungrazed or heavily grazed areas (Connell 1978, McNaughton 1979,
McNaughton 1993). Likewise, some investigators agree that compensatory growth of
plants can be observed in highly productive and intensively managed pastures, but not in
semi-arid rangelands (Bartolome 1993, DeAngelis and Huston 1993, Painter and Belsky 1993). On the other hand, there are many reports indicating that grazing disturbance results in ecological damage via reduction of primary production and associated disturbances such as animal trampling and erosion (Noy-Meir, 1993, Fleischner 1994, Kerley and Whitford 2000, Alados et al. 2004). Milchunas and Lauenroth (1993) reviewed 236 data sets world wide and found no clear relationship in species composition, root biomass, and soil nutrients (C, N) of grazed and ungrazed grasslands. Thus, there appears to be little or no consistency in the response of different grasslands to grazing (Milchunas and Lauenroth 1993, Milchunas et al. 1998, Jacobs 1999). However, productivity, evolutionary history of grazing of the site, and level of consumption explained more than 50% of the variance in the species response of grasslands to grazing (Milchunas and Lauenroth 1993).

There is a concern that highly concentrated livestock grazing around artificial water points contributes to processes that lead to desertification in rangelands (Holechek et al. 2000, Nangula and Oba 2004). According to Lange (1969), creation of piospheres leads to the development of a distinct ecological sub-system in which the interactions are determined by the existence of the water point and the ability of the animals to forage away from water. Jeltsch et al. (1997) indicated that piosphere zones expand outwards at a rate correlated with grazing pressure in semi-arid areas. Concentration of livestock at water points eliminates herbaceous cover and increased wind erosion (Nash et al. 2003). These heavily impacted areas are often desirable habitat for invasive exotic species to establish and spread (Pringle and Landsberg 2004). Lange (1969) suggested that understanding how to mitigate piosphere effects would be an important contribution to
the management of arid rangelands. An important question might be whether the changes induced under high and continuous grazing pressures are permanent or are able to improve once the grazing pressure is removed (Harrison and Shackleton 1999). It is therefore important to determine and monitor the impact of livestock grazing on rangelands in general, and piospheres in particular (Pringle and Landsberg 2004).

In the past, the Allideghi grassland has served as a temporary wet-season grazing area for the Afar pastoralists in the region. Because of a lack of permanent water, herds traditionally grazed the Allideghi Wildlife Reserve (AWR) and drank from ephemeral streams flowing to the plains from adjacent mountains during a few months of the year (see Chapter 2). This pattern has changed, however, with the establishment of artificial water points. Permanent settlements were established on the interior of the AWR about 30 years ago in conjunction with the establishment of a commercial livestock holding ground (Getachew 2001). According to Afar elders, there were only a few people living permanently in the AWR during that time. However, in the past 10 years the number of permanent settlers and their livestock has increased in five villages, each associated with a borehole. Settlement occurred as a result of growth in the pastoral population, annexation of other pastoral grazing lands, and enhanced pastoral competition for resources (Getachew 2001). Changes in the condition of the rangeland surrounding the artificial watering points are now obvious at AWR, as large areas have become denuded piospheres (A. Kebede, personal observation).

It is important, however, to conduct careful work to determine the impacts of livestock grazing on the herbaceous vegetation at AWR. How does concentrated livestock grazing gradually alter the composition, species richness, and productivity of
herbaceous vegetation? Can vegetation recover from such pressure if protected? To address these issues, a study site was selected in the central part of the AWR that included a large piosphere (over 280,000 m²) surrounding a settlement of about 2,500 people and probably over 3,000 livestock. This settlement is called “Allideghi Village.” Adjacent to the Allideghi Village is a 20 km² fenced area that has served as a holding ground for small number of livestock intended for export by a private corporation. This holding ground could serve as a useful “control” site.

The AWR has had little in the way of range research. The grassland is dominated by perennials such as _Chrysopogon plumulosus_ and _Sporobolus ioclades_. On the edges of the plain, the wooded grassland and shrublands comprise predominantly _Acacia_ species. Recently, _P. juliflora_ is becoming the dominant woody species in some parts of the grassland (A. Kebede, personal observation).

**Objectives, Hypotheses, and Predictions**

**Objectives**

Determine the direct effects of livestock grazing on standing crop biomass, biomass composition, utilization, above ground net primary productivity (ANPP) and species richness of herbaceous vegetation along a grazing gradient associated with a livestock-induced piosphere on the Allideghi grassland over one growing season.

**Hypotheses and Predictions**

The hypotheses (H) and the associated predictions (P) were as follows:
H1: The degree of forage utilization of the herbaceous vegetation increases, and standing-crop biomass decreases, both in a linear fashion, as livestock grazing pressure increases.

P1: Forage utilization increases with proximity to the water point, and standing-crop biomass increases as distance from the water point increases.

H2: ANPP of the herbaceous layer decreases in a linear fashion as livestock grazing pressure increases. Alternatively, ANPP may peak at an intermediate level of grazing pressure.

P2.1: ANPP of herbaceous vegetation decreases with increased proximity to the water point.

P2.2: ANPP is highest at sites located at intermediate distances from the water point with moderate grazing intensity.

H3: Composition of the herbaceous layer changes from grass-dominated to forb-dominated as livestock grazing pressures increases.

P3: The relative proportion of forb biomass increases with proximity to water point and that of grass increases as distance from the water point increases.

H4: Species richness of the herbaceous layer decreases in a linear fashion as livestock grazing pressure increases. Alternatively, the richness of species is highest at intermediate livestock grazing pressure.

P4.1: Species richness of herbaceous vegetation decreases with proximity to the water point.
P4.2: The species richness is highest at moderately grazed sites.

Materials and Methods

Historical Background of Livestock Grazing at AWR

Getachew (2001) conducted a detailed study on traditions and socio-economic change among the Afar pastoral communities of the Amibara District where AWR is located. The Awash Valley was predominantly inhabited and used by Afar pastoralists until the 1950s (Getachew 2001). After this, large-scale irrigated farms were established on the prime grazing lands previously used by Afar pastoralists. The Amibara-Melak-Saddi Irrigation Farm was established in 1969 in the Middle Awash and large-scale mechanized farming was expanded during the Ethiopian Derge Regime (1975-91) with the aim of alleviating food shortages as an alternative to smallholder farming and pastoralism (Getachew 2001).

According to Getachew (2001), the population of Amibara district in 2001 was about 86,000 including the Afar as well as members of other ethnic groups who came to the area after the establishment of the agricultural schemes. Even though data on livestock numbers differs from source to source, it is estimated that for 2002 there were about 112,978 livestock in total comprised of 19,655 cattle, 28,139 sheep, 56,278 goats, 8,431 camels and 475 donkeys living in Amibara District (OXFAM Ethiopia 2002).

Prior to the establishment of the large-scale irrigation schemes, the Afar lived close to the Awash River for most of the year. The Awash River is the only permanent water in the area. Traditionally, the Afar moved to the Mount Fentale area of Awash National Park and the Allideghi Plains for a few months during periods of rain and
floods. However, the establishment of Amibara-Malka-Saddi Irrigation Farm and associated settlements dislocated many Afars from their dry-season pastures. This led to frequent conflicts among the Afar clans and their neighbors (Issa, Kereyou, Ittu, and Argobba) over key resources (Getachew 2001).

There have been three major permanent settlements (villages) established in recent years on the Allideghi Plains: Allideghi, Udula Issae, and Andido. Another village with permanent water and school was being established on the plain during the field work of this study. The livestock from these settlements have permanent water from boreholes and are now using the area for most of the year. The livestock from these and other areas within the district also forage on crop residues at the irrigation farms for about one month per year after cotton is harvested (A. Kebede, personal observation).

**Site Selection**

This study estimated the impact of livestock grazing on the standing crop biomass, primary production, utilization, and species richness of herbaceous vegetation at different grazing intensities. The impacted areas were categorized based on the basal cover of the herbaceous vegetation at the end of the dry season at different distances from a central watering point along four transects. The selection of sites was thus not based on predetermined distances.

When assessing a gradient of grazing effects, researchers commonly use transects and sampling points that are systematically located on a landscape radiating in all directions from watering points (Fusco et al. 1995, Mphinyane 2001, Nangula and Oba 2004, Hendricks et al. 2005). In this work, a systematic approach was not used for several
reasons. First, transects that provided full coverage of a circular piosphere were not possible because the piosphere associated with the Allideghi Village did not have a uniform influence on the environment. Major livestock trails occurred to the south, extreme woody encroachment occurred as a large patch to the northwest, the fenced holding ground occurred to the west, and a zone of insecurity because of the conflict between Afar and Issa occurred further to the east. Hence, four transects were restricted to the north, northeast, east and southeast where livestock effects appeared more uniform and where fenced exclosures could be supervised and protected. In addition, sampling plots along transects were located at apparent thresholds where basal cover markedly changed, rather than at regular intervals. The four levels of livestock impact were categorized based on vegetation cover as follows:

i. Severely grazed - this category includes areas very near (≤ 300m) to the central settlement and watering site. The sites are mostly bare ground and with <10% basal vegetation cover.

ii. Heavily grazed - this category is a little further from the settlement (350 to 1,000 m). The sites have >10% and <50% basal cover, but no flowering stalks.

iii. Moderately grazed - this category is further out (2,000 to 3,000 m). Sites have ≥ 50% cover, and some flowering stalks are evident from the previous growing season.

iv. Control (ungrazed) - this is the permanently fenced area protected from grazing since 1997. It is just next to the core settlement area. In this site the only grazing is effected by the occasional wild herbivore (gazelles) that jumps the fence. In addition, a very few sheep and goats occasionally graze the site at the eastern
edge where some employees of the export firm are living. These animals largely rely on cut and carry grass. Areas for this research were selected on the western side of the site which is unused by livestock.

v. It was originally intended to include a fifth category of livestock impact referred to as “lightly grazed.” This was not incorporated, however, as sites that conform to “lightly grazed” are located in a “no-man’s land” between the conflicting Afar and Issa tribes, although the area technically belongs to the Afars. It would have been difficult to erect and maintain fences in these sites given insecurity (A. Kebede, personal observation)

As previously mentioned, the 20 km² fenced area at AWR serves as a holding ground for small ruminants destined for both export and domestic use by ELFORA Agro-Industries PLC. According to Ato Kassahun Mekonen, head of the Allideghi ELFORA Station, this holding ground was established in the early 1960s. It was owned by the government and well protected during the Derge Regime (1975-91). During a government change-over in 1991, the fence was destroyed by the local people and livestock had free access for grazing until 1996. ELFORA began to lease the site from the present government in 1997 and erected a new fence to establish complete protection from livestock soon after. There are some *P. juliflora* plants growing inside the site, especially in places adjacent to the settlement when livestock had resided from 1991 to 1997. Otherwise, the plant community is grassland.

**Research Design**

Three zones were identified at different distances from the main settlement and watering site based on the intensity of grazing: severely grazed, heavily grazed and
moderately grazed. As previously noted, these zones were delineated based on the percent basal cover of vegetation. In each zone, four representative study sites were selected on a restricted-random basis. These sites were selected to be representative, yet they also needed to avoid permanent livestock trails and other unusual disturbances. At each of the sites a 3 x 3 m exclosure was established (Figure 3.1). A paired site was also located adjacent to each exclosure. These paired sites were used to help determine forage utilization as well as impacts of grazing on standing-crop biomass and species richness of herbaceous vegetation over one growing season.

Similarly, four sites with exclosures and paired sites were randomly selected inside the ELFORA fenced site. This area served as a “control” to determine the potential of the area in terms of productivity and species composition of the herbaceous layer without recent influence of livestock grazing. In sum, the study was designed with three treatments and a control, each with four replicates (see Figure 3.1 for diagrammatical presentation).

Determining Productivity, Utilization, and Species Richness

Biomass production, forage utilization, and species composition were determined following procedures of Buttolph and Coppock (2004) and Osem et al (2002). At the end of the long dry season in June, and at the end of the growing season in October, species richness and standing biomass were determined in each of the exclosures as well as the paired sites.

For estimating available biomass, each exclosure and paired open sites were divided into four parts. Standing biomass was determined in June by clipping the
herbaceous vegetation from two randomly selected, 50 x 50 cm quadrats from each quarter in each exclosure and the paired sites. Then, the herbaceous layer was allowed to grow for three months (July, August, and September) during the growing season. At the end of the growing season, the aboveground productivity of the herbaceous layer was estimated by clipping the vegetation from two randomly selected, 50 x 50 cm quadrats in each quarter from places not previously harvested.

Similarly, species richness was determined from the paired sites outside the exclosures along the grazing gradient both in June and in October at the end of the growing season. The available biomass of the herbaceous vegetation was also estimated from randomly selected equivalent size and number of quadrats at the end of the growing season.

The number and kind of species in each quadrat was documented and the clipped vegetation was separated into grass and forb components to determine the contribution of grasses and forbs to species richness, ANPP, and utilization. The clipped vegetation was air-dried for two days. Then, sub-samples were oven dried for 48 hours at 80 °C at Addis Ababa University to provide dry-weight correction factors. Then, dry-weight values (g/m²) were calculated for both grass and forb categories for each sub-sample. The eight sub-samples from each exclosures and adjacent open areas were then combined into one value (g/m²).

The impact of livestock grazing on biomass production and species richness of the herbaceous layer was analyzed by comparing the results along the livestock grazing gradient and with the results obtained from the control site for 110 days. The recovery
potential of the herbaceous vegetation at different livestock grazing intensity was also
determined after protecting it from livestock grazing for one growing season.

Forage utilization for that specified period of time was estimated from the
difference in the available standing biomass outside the exclosures and the amount
produced inside the exclosure along the livestock grazing gradient at the end of the
growing season.

*Determining Forage Value*

Examining the role of traditional ecological knowledge of pastoralists in resource
management is becoming increasingly important, though little is known on how to apply
this knowledge (Fernandez-Gimenez 2000). According to Fernandez-Gimenez (2000),
pastoralists in Mongolia classify pasture areas using a number of criteria, including the
nutritional quality of the forage and their suitability to different types of livestock,
distance from camp, and others. They also identify a particular plant, its location, its
palatability and other vegetation characteristics. Thus, forage preference exercises were
conducted with pastoralists in this study on the value of major forage species, and
identification of “undesirable” species to allow quantification of forage value and help
interpret implications of species change.

Eleven forage species were identified based on the abundance of species along the
livestock grazing-gradient. These species were collected with their inflorescences to
allow species identification at the site by the author and later confirmed at the National
Herbarium in Addis Ababa. Two focus group discussions were conducted to rank the
species based on their perceived forage value (Gemedo-Dalle et al. 2005). Matrices were
prepared to compare and rank the forage value of each species from highest to lowest. Key informants were also asked to rank all the species in terms of their perceived nutritional value (as 1st, 2nd, … 10th). Forage value rankings were contrasted with pattern of herbaceous species change along the livestock grazing-gradient.

Statistical Analyses

For analysis of standing crop, ANPP and utilization (across 110 days), data from the eight sub-plots from each exclosure and the paired plots were combined and averaged to one value (g/m²; S. Durham, personal communication). For determining species richness, the different species from each of the eight subplots were combined into one value (number of species/8 x 0.25m² subplots).

The quadrat samples from all four levels of grazing intensity (N=16, collapsed from 128 quadrats), both inside and outside the exclosures, and at the end of dry and wet seasons (a total of 64 quadrat samples), were used for analysis of standing-crop biomass. All data were tested for normality and appropriately transformed when necessary prior to analysis. For estimation of standing biomass, ANPP, utilization, and species richness data were normalized using natural logarithms (Faraway 2005). Data were analyzed using the R Statistical Package (R 2.5.1). A Linear Mixed-Effect (LME) model was fit using a Restricted Maximum Likelihood Estimation (REML; Faraway 2005). A three-way analysis of variance (ANOVA) was then used to check the fixed effects (intensity of grazing, season, and inside/outside of exclosures) and their interactions for significance concerning standing-crop biomass. A one-way ANOVA was used to test the significance for ANPP and forage utilization at different grazing intensities. Tukey’s HSD post-hoc
test was used for multiple comparisons of means when significant differences were detected with ANOVA. Grazing intensity, inside/outside of exclosures, and seasons (June and October) were fixed effects whereas plot and pair identifications were random effects.

Results

Synthesized results are provided in this section. See Appendix C for detailed statistical analyses.

Precipitation

The precipitation received for the study period is illustrated in Figure 3.2. As mentioned in Chapter 1, over the past 36 years, annual rainfall has ranged from 336 to 819 mm with a mean value of 569 mm according to meteorological data from EARO at Melka Werer. The rainfall is bimodal with the most rain received in March/April and July/August. The total annual rainfall for 2005 was 791 mm, which was markedly above the long-term average, but well within the range of the historical variation. The rainfall in 2005 was also bimodal. During the long rainy season (July, August and September), the area obtained an average amount of rainfall (307 mm). During drought years, the area received as low as 158 mm rain in these months and in good years as high as 450 mm. Therefore, the results of this study do not indicate the two extreme conditions.

Standing-crop Biomass

Standing-crop biomass for both sampling times is shown in Table 3.1. At the end of the dry season (June) total herbaceous and grass biomass increased markedly (p<0.001) from the severely grazed condition to the control (Table 3.1; Figure 3.3). In
contrast, there were no significant differences of forb biomass along the gradient. There were no significant differences (p>0.05) between paired plots inside and outside exclosures for any attributes. This indicates that paired sites were appropriately similar since the biomass was taken at the same time before effects of fencing had occurred.

The most important standing-crop data were collected in October because they illustrated treatment effects (Table 3.1). Total herbaceous and grass standing-crop decreased as grazing intensity increased with proximity to settlement and watering site (Table 3.1; Figure 3.4). In contrast, forb biomass significantly increased at severely grazed sites (p<0.05). Outside the exclosures sites showed similar biomass levels to that observed in June (p>0.05).

As shown in Table 3.1, total biomass, and grass biomass inside the exclosures, steadily increased from the severely grazed site to the control. There was a 5.4-fold increase in total biomass that occurred as a result of a 111-fold increase in grass biomass from the severely grazed site to the control. Forbs, in contrast, declined by 68% along the same grazing gradient. Overall, long-term effects of grazing radically transformed the vegetation from about 94% grass and 6% forbs in the control sites to 4% grass and 96% forbs in the severely grazed locations (Figure 3.5).

In general, total standing-crop biomass for both June and October, respectively, decreased steadily from ungrazed (100%) to moderately grazed (62%, 74%), heavily grazed (20%, 49%), and severely grazed areas (5%,18%; Figure 3.3 and 3.4). Increased biomass in October occurred as a result of the 306 mm rainfall received during July, August, and September. Table 3.2 shows significant increase in grass biomass between
June and October (p<0.05) at all sites inside the exclosures. However, forb biomass increased significantly at severely grazed areas as a result of fencing.

A three-way interaction of the main factors (p=0.005) illustrates that the total standing-crop was significantly higher following grazing exclusion at severely, heavily, and moderately grazed sites. Control sites maintained the highest standing-crop both inside and outside the exclosures except for the seasonal difference due to senescence (Table 3.2; Figure 3.6).

Sites at the settlement and watering source had 99% of the herbaceous vegetation, and 100% of the grass biomass, removed via grazing and trampling (Figure 3.5). The proportion of forbs in total herbaceous vegetation was 7%, 7%, 8%, and 18%, at the control, moderately, heavily and severely grazed sites, respectively.

Total biomass increased significantly at all grazed sites after protection for one growing season (p<0.05; Table 3.4). Percentage of biomass in October, compared to that of the control as a measure of potential herbaceous recovery, increased as the intensity of grazing decreased: highest at moderately grazed sites (74%) and lowest at severely grazed sites (19%). Nearly all (96%) of the protected vegetation at the severely grazed sites was forbs.

**Utilization of Herbaceous Vegetation**

Utilization of the herbaceous vegetation for 110 days was estimated by comparing the standing crop biomass inside and the adjacent open area outside the exclosures. There were significant differences (p<0.05) between the biomass obtained inside and outside the exclosures along the grazing gradient except for the control because of utilization by livestock (Table 3.3). In June, on average, 95%, 83%, and 47% of the herbaceous
biomass was used at severely, heavily and moderately grazed sites, respectively, compared to the control sites. In October, 68%, 66%, and 54% of the standing-crop biomass was grazed within 110 days following the same grazing gradient, respectively.

The amount of biomass utilized increased significantly with the increase in distance from the water point (Figure 3.7a); however, the percentage of biomass utilized from the standing biomass was highest at intermediate distance from the water point (heavily grazed sites) and lowest at the moderately grazed sites (Figure 3.7b).

**Aboveground Net Primary Productivity (ANPP)**

Aboveground net primary productivity (ANPP) was measured for 110 days after the long rainy season. The total ANPP of exclosed plots at the heavily and moderately grazed sites was not significantly different from that of the controls (p>0.05). However, grazing affected (p< 0.001) the productivity of severely grazed areas (Table 3.4). The ANPP at severely grazed sites was only 37% of that for control sites.

Perennial grass species were absent from the severely grazed sites. Forb ANPP at severely grazed sites was significantly higher (p<0.05) than that for other sites along the grazing gradient. The percentage contribution of grasses to the total ANPP increased along the grazing gradient (Figure 3.8a-d). It was highest in the control sites (96%) and lowest at severely grazed sites (5%). In contrast, the contribution of forbs to the total ANPP was highest at overgrazed sites (95%) and lowest at the control sites (4%).

**Species Richness**

The number of species decreased with the increase in grazing intensity (Figure 3.9) but the relationship was not significant at heavily and moderately grazed sites. The
mean number of species at severely grazed areas was significantly lower (p<0.05) both in June (2.5 species) and October (4.3 species) than that at other sites (Table 3.6). The contribution of grasses was relatively lower than that of forbs. A maximum number of three grass species was found on moderately grazed and ungrazed sites. In June, there were no grass species at severely grazed sites. However, only one grass (C. ciliaris) was found in October on severely grazed sites. The number of forbs, which had the highest contribution to biomass on severely grazed sites, was significantly lower (p<0.01; 3.5 species) than in other sites (8-9 species).

Forage Quality

It was only possible to document a few important forage species using the focus group methodology. The pastoralists consider one of the dominant grasses, C. ciliaris, as the most important forage source during the wet season, even though its persistence during the dry season is poor. After C. ciliaris senesces during the dry season, the dominant perennial Chrysopogon plumulosus becomes a very important forage source. The pastoralists also consider Cympopogon sp. as having a high feed value for camels in spite of its restricted distribution along the main highway. They also mentioned perennial grasses such as Lintonia nutans, Panicum coloratum, and Sporobolus ioclades as important during the dry season. The most important forb they mentioned was the short-lived annual Ipomoea sp., and it is of value for camels. All the species mentioned, except Cympopogon, were observed along the transects.
Discussion

Piosphere

Provision of permanent drinking water for humans and livestock on the Allideghi Plain, where there was no permanent source of natural water, has resulted in increased settlement and heightened livestock grazing pressure over the past three decades. This study showed that the concentrated continuous impact of livestock grazing and trampling around an artificial watering point at AWR has had significant effects on the herbaceous vegetation. A sacrifice zone or piosphere has been created exceeding 28 hectares in size, which is about 0.03% of the Allideghi Plain (84,680 ha) overall.

In this zone, where livestock drink water and spend the night most of the year, there was little or no standing biomass even at the end of the growing season. Research in South Africa, Australia and Somalia indicates that rangeland condition, herbaceous community composition, and forage production potential decline severely as one approaches artificial watering points (Foran 1980, Barker et al. 1989, Thrash et al. 1991, 1993). Thrash (1998) noted that artificial watering points can be the foci of much greater rangeland degradation than are natural seasonal sources of water.

Standing Crop Biomass and Composition

The standing crop biomass for unprotected plots steadily declined from the control to the severely grazed sites; this indicated that selection of plots represented a grazing gradient. The standing crop biomass for protected plots at the end of the wet season also steadily declined along the same sequence, indicating long-term-effect of grazing and trampling. Both patterns thus conformed to predictions. Floyd et al. (2003) and Fleischner (1994) reported that heavy grazing reduces standing biomass in rangeland
systems. Floyd et al. (2003) also noted that reductions in the standing biomass can accelerate soil erosion.

The composition of standing biomass both in unprotected and protected plots over 110 days underwent dramatic change from grass domination (94% at ungrazed sites; control) to forb domination (96 to 100% at severely grazed sites) near the watering site. However, the shift did not occur until the severely grazed condition, suggesting that herbaceous composition was somewhat resistant to repeated defoliation, except in areas near the watering site with severe grazing and trampling. The change from grass- to forb-dominance under heavy grazing regimes is consistent with the prediction of this study. Such change in species composition due to intensive livestock grazing has been observed by other investigators on the steppe of Southern Sweden (van der Maarel and Titlyanova 1989), in the perennial grasslands of Australia (McIntyre and Lavorel 2001), and Chihuahuan desert (Fusco et al. 1995).

At the severely grazed sites nearest the watering site, the perennial grass species could not tolerate the effects of heavy grazing and continuous trampling and thus such areas were dominated by an annual forb, *Tribulus terrestris*. *Tribulus terrestris* is found associated with soil disturbance and higher soil fertility, where animals concentrate their dung or urine and repeatedly disturb the ground (Mphinyane 2001). Similarly, in the grasslands of Botswana, heavy grazing and trampling around water points killed perennial grasses (Mphinyane 2001). Hendricks et al. (2005) also reported that palatable plant species which are sensitive to heavy grazing and trampling declined near stock posts. The repeated impact of livestock grazing decreased the potential of perennial
grasses to compete with forbs for resources (Hayes and Holl 2003) and prevent seed
production to replenish their seed bank (Zaady et al. 2001).

**Utilization**

Patterns of utilization for the 110-day wet season indicated that removal of forb
biomass steadily increased over the grazing gradient, while that for grasses decreased.
This was consistent with the changing availability of forbs and grasses in the standing
biomass along the grazing gradient. Percent utilization varied in grazed locations, but was
well above 60% of the total standing biomass, except at the moderately grazed sites
(<50%). The pattern again confirmed the presence of a grazing gradient as related to the
piosphere, with the heaviest use tending to occur at the intermediate levels of impact
(heavily grazed).

Other investigators (Adler and Hall 2005) also noted peak utilization at moderate
distances from water points and lowest utilization as the distance increases, and this
agrees with observations in this study. This highest degree of utilization at heavily grazed
sites (moderate distance) might be because of the high nutritional quality and digestibility
of new shoots compared with the old shoots and coarse stems at moderately grazed and
ungrazed sites (Westoby 1986, Karki et al. 2000, Mphinyane 2001) and lack of palatable
forage at the severely grazed sites. The higher utilization at severely grazed sites might be
due to the low available biomass and the loss through trampling (Mphinyane 2001).

**Productivity**

For ANPP, it was predicted that there could be two likely outcomes, either a
linear decline with increasing grazing pressure approaching the watering site (Adler and
Hall 2005), or an optimization where production would peak at an intermediate level of herbivory (McNaughton 1976, 1979, 1993). The results of this study do not support both hypotheses. Rate of ANPP for grasses and total herbaceous vegetation appeared to plateau from the control to heavy levels of grazing, before markedly declining at the severe level of impact. This provided more evidence concerning the resistance of the community to herbivory where there was little vegetation left undamaged from livestock grazing and trampling.

Mechanisms that may account for the response of plants to compensate for the negative impacts of livestock grazing and stimulate the relative growth rate of defoliated plants include increase in the availability of light (which increases the photosynthetic rates of the remaining leaves at the base of the canopy), increased photosynthetic efficiency and allocation of photosynthates to new leaves, and activate the dormant meristems when apical meristems are removed (McNaughton 1979, Noy-Meir 1993). In addition, the ability of vegetation to maintain ANPP at moderate grazing intensities might also be due to the fact that the Allideghi grassland is flat and appears to be an ecosystem sink where soils are replenished with moisture and nutrients flowing from adjacent, higher-elevation landscapes (de Queiroz et al. 2001).

At the same time, at higher grazing intensities (severely grazed sites), ANPP was significantly lower than the values under other grazing intensities. Other studies in similar semi-arid ecosystems also indicate that ANNP decreases as distance from the watering site decreased and intensity of grazing increases (Fusco et al. 1995 [Chihuahuan desert], Landsberg and Stol 1996 [Australia], Mphinyane 2001 [Botswana], Landsberg et al. 2003 [Australia]. At Allideghi, the photosynthetic activity of the plants at severely
grazed sites was very low due to heavy loss of shoots and roots of the herbaceous vegetation through grazing and trampling (van der Marrel and Titlyanova 1989, Briske 1991, Noy-Meir 1993) and thus the losses of biomass could not be recovered by re-growth (Manseau et al. 1996). The other mechanisms as to how grazing negatively affects growth rates and production of plants include removal of active apical meristems that acts as sinks for photosynthates and produce new shoot tissues, and loss of nutrients for growth stored in the shoot (Noy-Meir 1993).

Species Richness

It was predicted that there also could be two likely outcomes for the impact of grazing on species richness. These include either a linear decline with increasing grazing pressure (Hendricks et al. 2005), or an increase in species number due to disturbance at intermediate levels of herbivory because of disturbance-mediated vegetation dynamics (Laska 2001, Bagchi et al. 2006). The results of this study do not support either hypothesis. Total species, and number of grass species were similar from the control to heavy levels of grazing and significantly declined at severely grazed sites. This is also another indication of the resilience of the grassland at a landscape scale.

Similarly, species richness and frequency of occurrence of native species declined with increasing proximity to watering sites in Australian grasslands (Landsberg et al. 2003). Other researchers also indicated that intensive livestock grazing reduces the abundance and species richness in native pastures (Manseau et al. 1996, McIntyre et al. 2003, Hendricks et al. 2005). Floyd et al. (2003) also found higher species richness in ungrazed areas with long-term protection than in areas which are currently being grazed.
Such trend might indicate that intensive livestock grazing might be a threat to the biodiversity of rangelands (Pringle and Landsberg 2004). However, Saberwal (1996) recognized the impact of livestock grazing around corrals in lowering species diversity, but argued that the impact is insignificant at the landscape level.

*Forage Quality*

The focus group survey on the palatability of forage was not successful in terms of revealing specific quality of ranking of herbaceous species. The people were not able to rank all the eleven species presented to them as first, second, etc. Rather, they indicated in general that *C. ciliaris* is highly nutritious during the wet season, as is *C. plumulosus* both in wet and dry seasons. Duke (1983) also reported that *C. ciliaris* is highly nutritious and valued for its high production of palatable forage in the tropics during wet seasons, and intermittent grazing during dry periods because of its low persistence. In Ethiopia's Awash National Park, it was found that the nutritional quality of *C. plumulosus*, as measured by its crude protein content, was above or at the maintenance level for ruminants most of the year, except during the long dry season (Kebede 1997). According to Pratt and Gwynne (1977), *C. ciliaris* and *C. plumulosus* are among the most valuable grazing species in east Africa.

*Community Resilience*

The best evidence for the resilience of this grassland comes from the control site, which was once highly impacted by livestock. After one season of protection, the heavily and moderately grazed sites exhibited standing biomass, ANPP and species richness that were not significantly different from that of the control site, which had been protected for
eight years. However, the severely grazed sites near the water point would need more than one growing season to fully recover from livestock impacts. Following the removal of high and continuous grazing pressure from communal lands in semi-arid grasslands of South Africa (with annual rainfall ranging from 580-680 mm, similar to the Allideghi area), Harrison and Shackleton (1999) found that most changes in grass species composition occurred with four to nine years of protection. They found that the abundance of perennials showed a significant increase with time since protection, while the abundance of annuals showed a simultaneous decrease. In Botswana, Dahlber (2000) also showed that after only four years rest from grazing, the productivity of communal grazing areas substantially increased and several species described as indicators of good grazing condition had become well established. Thus, despite the pervasive effects of concentrated livestock use, it is apparent that the herbaceous community on the Allideghi grassland has a substantial ability to recover should livestock pressure be reduced or eliminated. This is probably due to the fact that the grassland is replenished with moisture and nutrients from the adjacent mountains areas (de Queiroz et al. 2001).

Conclusions

The traditional pastoral system which enabled intensively grazed sites to rest periodically was an important component of sustainable use of the grassland. However, provision of artificial sources of water increased the number of humans and livestock settling at Allideghi permanently. The repeated grazing and trampling of livestock at the artificial watering point has created a sacrifice zone which has little or no forage value. Next to this is a zone where all the perennial grasses, once dominant, are totally
eradicated and replaced with unpalatable forbs. At this zone, the reduction of valuable forage biomass is >90%. In Australian rangelands, proliferation of artificial watering points also created consistent and substantial changes in plant productivity and composition related to the accumulated long-term impacts of water-centered grazing (Landsberg et al. 2003).

Even though this study suggested that the grassland is resilient to the impacts of livestock grazing, the trend whereby more people and livestock are settling permanently in the area undermines system integrity. Livestock travel longer distances to increase their range of grazing as forage becomes scarce. To maximize foraging orbits livestock can be herded back villages every-other-day for water, rather than daily. The creation of a sacrifice zone and an adjacent area dominated with unpalatable forbs force livestock to travel further to get their daily forage requirement. Because grasses comprise a high proportion of cattle diets (Austin and Urness 1986, Odadi et al. 2007) such a foraging pattern will ultimately increase the size of the core impacted zone.

In addition, lack of palatable forage near the watering site was shown by the heavy utilization (73% of the standing biomass in 110 days) at heavily grazed sites. This might be a sign that the impact will expand on the heavily grazed extensive area even though it seems it has currently resisted the impact. In addition, there is no guarantee to limit the number of artificial watering sites in the future. A new settlement with an artificial water source and school was being established on the plain during the study period (A. Kebede, personal observation).

As mentioned, AWR is the only refuge left in the area for wild animals, and AWR is especially important for the endangered Grevy’s Zebra. It is also becoming the most
important forage source for livestock in the district. The sustainability of the grassland to support both wild and domestic animals in the future will be uncertain if the current trend of new settlements and artificial water sources continue. Thus, it is important if the future management plan of the AWR considers this issue and its long-term impact on the vegetation. It is also necessary for both the local and regional governments to work with the people to limit permanent settlements based on the carrying capacity of the area.

References


dynamics and livestock productivity in an Andean pastoral ecosystem. - J. Appl.
Ecol. 41: 664-74.


Dahlberg, A.C. 2000. Vegetation diversity and change in relation to land use, soil and
rainfall- a case study from North-East District, Botswana. - J. Arid Environ. 44:
19-40.


of San Jose Llarga. In: Coppock, D.L. and Valdiva, C. (eds), Sustaining
agropastoralism on the Bolivian Altiplano: The case of San Josi Lianga.
Department of Rangeland Resources, Utah State University, pp. 59-115.


Ecol. Appl. 3: 10-16.

paradigms and implications for development. - J. Range Manage. 41: 450-459.

Faraway, J. J. 2005. Extending the linear model with R: generalized linear, mixed effects

Fernandez-Gimenez, M.E. 2000. The role of Mongolian nomadic pastoralists' ecological

Fleischner, T.L. 1994. Ecological cost of livestock grazing in western North America. -

on vegetation at Chaco Culture National Historic Park, New Mexico. - Conserv.
Biol. 17: 1703-1711.

Foran, B.D. 1980. Change in range condition with distance from watering points and its

Fusco, M., Holechek, J., Tembo, A. et al. 1995. Grazing influences on watering point


Thrash, I. 1998. Impact of large herbivores at artificial watering points compared to that at natural watering points in Kruger National Park, South Africa. J. Arid Environ. 38: 315–324


van der Maarel, E. and Titlyanova, A. 1989. Above-ground and below-ground biomass relations in steppes under different grazing conditions. - Oikos 56: 364-370.


Table 3.1. Aboveground, standing-crop biomass (g/m$^2$)\(^1\) for herbaceous vegetation, inside and outside of the exclosures, and along a grazing gradient\(^2\) at Allideghi Wildlife Reserve (AWR), Ethiopia, during June and October, 2005.\(^3,4,5\)

<table>
<thead>
<tr>
<th>Category</th>
<th>Grazing Intensity</th>
<th>June Inside</th>
<th>S.E</th>
<th>June Outside</th>
<th>S.E</th>
<th>October Inside</th>
<th>S.E</th>
<th>October Outside</th>
<th>S.E</th>
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<td></td>
<td>Mean</td>
<td>Mean</td>
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<td>Mean</td>
<td></td>
<td>Mean</td>
<td></td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Severe</td>
<td>13.8(^a)</td>
<td>3.19</td>
<td>13.7(^a)</td>
<td>2.75</td>
<td>87.5(^{aA})</td>
<td>10.71</td>
<td>28.2(^{al})</td>
<td>4.91</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>53.9(^b)</td>
<td>6.91</td>
<td>50.6(^b)</td>
<td>6.42</td>
<td>231.2(^{bA})</td>
<td>9.36</td>
<td>79.0(^{bb})</td>
<td>11.02</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>167.0(^c)</td>
<td>4.08</td>
<td>138.5(^c)</td>
<td>24.19</td>
<td>348.4(^{bcA})</td>
<td>6.20</td>
<td>158.1(^{cB})</td>
<td>7.33</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>270.2(^c)</td>
<td>33.48</td>
<td>294.5(^c)</td>
<td>50.04</td>
<td>470.9(^{bcA})</td>
<td>97.08</td>
<td>482.2(^{daA})</td>
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<td>0.29(^a)</td>
<td>0.11</td>
<td>3.8(^{aA})</td>
<td>2.04</td>
<td>0.6(^{aA})</td>
<td>0.33</td>
</tr>
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<td>Heavy</td>
<td>32.8(^b)</td>
<td>3.88</td>
<td>33.8(^b)</td>
<td>3.73</td>
<td>188.9(^{bA})</td>
<td>6.87</td>
<td>48.6(^{bb})</td>
<td>5.91</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>156.9(^c)</td>
<td>1.39</td>
<td>123.0(^c)</td>
<td>12.22</td>
<td>321.3(^{bcA})</td>
<td>7.61</td>
<td>136.8(^{cB})</td>
<td>5.03</td>
</tr>
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<td>Control</td>
<td>252.8(^c)</td>
<td>18.87</td>
<td>285.0(^c)</td>
<td>25.38</td>
<td>444.7(^{cA})</td>
<td>104.65</td>
<td>458.7(^{cA})</td>
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<td>3.19</td>
<td>13.5(^a)</td>
<td>2.66</td>
<td>83.7(^{aA})</td>
<td>10.69</td>
<td>27.7(^{ab})</td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>21.2(^a)</td>
<td>3.99</td>
<td>16.8(^a)</td>
<td>1.49</td>
<td>42.3(^{aA})</td>
<td>6.89</td>
<td>30.4(^{aA})</td>
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<td>5.07</td>
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<td>21.3(^{aA})</td>
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<tr>
<td></td>
<td>Control</td>
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<td>5.25</td>
<td>9.5(^a)</td>
<td>2.52</td>
<td>26.2(^{bA})</td>
<td>8.92</td>
<td>23.5(^{aA})</td>
<td>8.10</td>
</tr>
</tbody>
</table>

\(^1\) Oven dry weight. \(^2\) Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, and the control is a site fully protected from grazing for eight years. \(^3\) In June, there was no significant difference between inside and outside the exclosures in all cases. \(^4\) Means accompanied by the letters (a,b,c) in columns, or letters in rows (A, B, C) were not significantly different (p≥0.05) following Tukey’s HSD post-hoc significance test. \(^5\) Differences are indicated separately for total, grass, and forb biomass for both seasons.
Table 3.2. Summary of three-way ANOVA results of the Linear Mixed Model\(^1\) for grazing gradient\(^2\), season\(^3\), exclosure\(^4\) and their interaction for standing-crop biomass.

<table>
<thead>
<tr>
<th>Category/Treatments</th>
<th>numDF(^5)</th>
<th>denDF(^6)</th>
<th>F-value</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td><strong>Total</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Grazing</td>
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<td>106.137</td>
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</tr>
<tr>
<td>Season</td>
<td>1</td>
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<td>217.193</td>
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</tr>
<tr>
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<td>&lt;.0001</td>
</tr>
<tr>
<td>Grazing:Season</td>
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<td>24</td>
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<td>&lt;.0001</td>
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<td>0.0051</td>
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<tr>
<td>Season:Exclosure</td>
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<td>24</td>
<td>38.911</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Grazing:Season:Exclosure</td>
<td>3</td>
<td>24</td>
<td>5.191</td>
<td>0.0066</td>
</tr>
<tr>
<td><strong>Grass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>12</td>
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<td>24</td>
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<tr>
<td><strong>Forb</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing</td>
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<td>Season</td>
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<td>24</td>
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</tr>
</tbody>
</table>

\(^1\)Data were analyzed using the R Statistical Package (R 2.5.1) with a Linear Mixed-Effects model (LME) fit under a Restricted Maximum Likelihood Estimation (REML). \(^2\)Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% vegetation cover, and the control has been protected from grazing for eight years. \(^3\)The two seasons are June (end of the dry season) and October (end of the wet season). \(^4\)Inside or outside the exclosures. \(^5\)Numerator degree of freedom. \(^6\)Denominator degree of freedom.
Table 3.3. Utilization of herbaceous biomass (g/m²)¹ by livestock for 110 days during the growing season along a grazing gradient² at Allideghi Wildlife Reserve (AWR), Ethiopia.³

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>Utilization</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
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<td>Grass</td>
<td>Forb</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.E</td>
<td>Mean</td>
<td>S.E</td>
<td>Mean</td>
</tr>
<tr>
<td>Severe</td>
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<td>1.94</td>
<td>56.0</td>
<td>6.37</td>
<td>59.2</td>
</tr>
<tr>
<td>Heavy</td>
<td>137.8</td>
<td>5.59</td>
<td>14.4</td>
<td>4.15</td>
<td>152.2</td>
</tr>
<tr>
<td>Moderate</td>
<td>184.6</td>
<td>10.87</td>
<td>5.6</td>
<td>2.29</td>
<td>190.3</td>
</tr>
</tbody>
</table>

¹ Oven dry weight. ² Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, and moderately grazed is > 50% basal cover. ³ Means accompanied by the same letters (a, b, c) within columns were not significantly different (p ≥ 0.05) following Tukey’s HSD post-hoc significance test.

Table 3.4. Aboveground productivity (g/m²)¹ over 110 days during the growing season along a grazing gradient² at Allideghi Wildlife Reserve (AWR), Ethiopia.³

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>Productivity</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grass</td>
<td>Forb</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.E</td>
<td>Mean</td>
<td>S.E</td>
</tr>
<tr>
<td>Severe</td>
<td>3.8</td>
<td>2.04</td>
<td>69.9</td>
<td>7.53</td>
</tr>
<tr>
<td>Heavy</td>
<td>153.6</td>
<td>9.54</td>
<td>23.7</td>
<td>8.28</td>
</tr>
<tr>
<td>Moderate</td>
<td>164.4</td>
<td>8.59</td>
<td>17.1</td>
<td>3.38</td>
</tr>
<tr>
<td>Control</td>
<td>191.9</td>
<td>18.35</td>
<td>8.9</td>
<td>3.74</td>
</tr>
</tbody>
</table>

¹ Oven dry weight. ² Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, and the control was protected from grazing for eight years. ³ Means accompanied by the same letters (a, b, c) within columns were not significantly different (p ≥ 0.05) following Tukey’s HSD post-hoc significance test.
Table 3.5. Number of herbaceous species (no/2m²)\(^1\) of herbaceous vegetation, along a grazing gradient\(^2\) at Allideghi Wildlife Reserve (AWR), Ethiopia, during June - October, 2005.\(^3\)

<table>
<thead>
<tr>
<th>Category</th>
<th>Grazing intensity</th>
<th>June</th>
<th></th>
<th>October</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>S.E</td>
<td>Mean</td>
<td>S.E</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td>2.5(^{aA})</td>
<td>0.87</td>
<td>4.3(^{aA})</td>
<td>0.48</td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
<td>9.0(^{bA})</td>
<td>0.42</td>
<td>12.5(^{bB})</td>
<td>0.29</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>9.5(^{bA})</td>
<td>0.50</td>
<td>14.0(^{bB})</td>
<td>1.08</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>11.0(^{bA})</td>
<td>0.41</td>
<td>12.3(^{bA})</td>
<td>1.25</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td>0.0(^{aA})</td>
<td>0.00</td>
<td>0.75(^{aA})</td>
<td>0.25</td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
<td>2.0(^{aA})</td>
<td>0.41</td>
<td>3.5(^{bA})</td>
<td>0.65</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>3.0(^{bA})</td>
<td>0.41</td>
<td>4.25(^{bA})</td>
<td>0.75</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>3.0(^{bA})</td>
<td>0.41</td>
<td>4.25(^{bA})</td>
<td>0.75</td>
</tr>
<tr>
<td>Forb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td>2.5(^{aA})</td>
<td>0.87</td>
<td>3.5(^{aA})</td>
<td>0.29</td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
<td>7.0(^{bA})</td>
<td>0.00</td>
<td>9.0(^{bA})</td>
<td>0.41</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>6.5(^{bA})</td>
<td>0.65</td>
<td>9.8(^{bA})</td>
<td>0.75</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>8.0(^{bA})</td>
<td>0.58</td>
<td>8.0(^{bA})</td>
<td>1.35</td>
</tr>
</tbody>
</table>

\(^1\) Number of species per eight sub-quadrats of (2m²) in exclosures (mean± SE). \(^2\) Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, and the control was protected from grazing for eight years. \(^3\) Means accompanied by the same letters (a, b, c) within columns or letters in rows (A, B, C) were not significantly different (p≥0.05) following Tukey’s HSD Post-hoc significance test.
Table 3.6. Summary of two-way ANOVA results of the Linear Mixed Model\textsuperscript{1} for grazing gradient\textsuperscript{2}, season\textsuperscript{3}, and their interaction for number of species.\textsuperscript{4}

<table>
<thead>
<tr>
<th>Category/Treatments</th>
<th>numDF\textsuperscript{5}</th>
<th>denDF\textsuperscript{6}</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing</td>
<td>3</td>
<td>12</td>
<td>38.00</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>12</td>
<td>19.78</td>
<td>0.0008</td>
</tr>
<tr>
<td>Grazing:Season</td>
<td>3</td>
<td>12</td>
<td>2.07</td>
<td>0.1575</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing</td>
<td>3</td>
<td>12</td>
<td>29.94</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>12</td>
<td>27.40</td>
<td>0.0002</td>
</tr>
<tr>
<td>Grazing:Season</td>
<td>3</td>
<td>12</td>
<td>0.58</td>
<td>0.6407</td>
</tr>
<tr>
<td>Forb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing</td>
<td>3</td>
<td>12</td>
<td>19.32</td>
<td>0.0001</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>12</td>
<td>8.96</td>
<td>0.0112</td>
</tr>
<tr>
<td>Grazing:Season</td>
<td>3</td>
<td>12</td>
<td>1.70</td>
<td>0.2194</td>
</tr>
</tbody>
</table>

\textsuperscript{1}The data were analyzed using the R Statistical Package (R 2.5.1) with a Linear Mixed-Effects model (LME) fit under a Restricted Maximum Likelihood Estimation (REML). \textsuperscript{2} Where severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% vegetation cover, and the control was protected from grazing for eight years. \textsuperscript{3} The two seasons are June (end of the dry season) and October (end of the wet season). \textsuperscript{4} The number of species was estimated from a total area of 2 m\textsuperscript{2}. \textsuperscript{5} Numerator degree of freedom. \textsuperscript{6} Denominator degree of freedom.
Figure 3.1. Exclosure design for determination of the impact of livestock grazing and season on the standing biomass and productivity of the herbaceous layer at the Allideghi Wildlife Reserve (AWR), Ethiopia.

Settlement and watering site

Four quarters in each exclosures and the adjacent equivalent open area

Control (ungrazed site protected for 8 years)

Four transects were established that originated from the settlement. Exclosures were erected at three locations where intensity of grazing

Nine 0.5 m x 0.5 m subplots in each quarter
Figure 3.2. Monthly precipitation of 2005 compared with the mean monthly precipitation (mean ± SE) for 36 years from 1970 – 2005 (Source: Melka Werer EARO, unpublished).
Figure 3.3. (a-c). Aboveground, standing-crop biomass (g/m²) for herbaceous vegetation, inside and outside of the exclosures, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during June, 2005. Biomass is oven dry weight (x ±SE). Severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, and the control was protected from grazing for eight years. June is the end of the dry season.
Figure 3.4 (a-c). Aboveground, standing-crop biomass (g/m²) for herbaceous vegetation, inside and outside of the exclosures, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during October, 2005. Biomass is oven dry weight (±SE). Severely grazed is <10% basal cover, heavily grazed is ≥25% basal cover, moderately grazed is >50% basal cover, and the control was protected from grazing for eight years. October is the end of the growing season.
Figure 3.5 (a, b). Proportion of grass and forb aboveground, standing-crop biomass (g/m²) inside the exclosures in both seasons, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005. Biomass is oven dry weight (\( \bar{x} \pm SE \)). Severely grazed is <10% basal cover, heavily grazed is \( \geq 25\% \) basal cover, moderately grazed is > 50% basal cover, and the control was protected from grazing for eight years. June is the end of the dry season. October is the end of the growing season.
Figure 3.6. Aboveground, standing-crop biomass (g/m²) inside and outside the exclosures in both seasons, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005. Biomass is oven dry weight (±SE). Severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, and the control was protected from grazing for eight years. June is the end of the dry season. October is the end of the growing season.
Figure 3.7 (a, b). Utilization of aboveground of herbaceous vegetation (g/m²) for one growing season (110 days), along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005. Biomass is oven dry weight (mean±SE). Severely grazed is <10% basal cover, heavily grazed is ≥25% basal cover, moderately grazed is >50% basal cover. Utilization at the control site was negative since the standing biomass outside the exclosure was a little higher than that inside exclosure.
Figure 3.8. Aboveground productivity (g/m²) of herbaceous vegetation inside the exclosures after one growing season, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during October, 2005. Biomass is oven dry weight (x ±SE). The vegetation was allowed to grow for 110 days from end of June to October, 2005. Severely grazed is <10% basal cover, heavily grazed is ≥ 25% basal cover, moderately grazed is > 50% basal cover, the control was protected from grazing for eight years.
Figure 3.9. Number of species (No/2m²) of herbaceous vegetation, along a grazing gradient at Allideghi Wildlife Reserve (AWR), Ethiopia, during June and October, 2005. Number of species (mean±SE) over eight sub-quadrats (2m²) in exclosures. Severely grazed is <10% basal cover, heavily grazed is ≥25% basal cover, moderately grazed is >50% basal cover, and the control was protected from grazing for eight years. June is end of the dry season. October is end of the growing season.
 CHAPTER 4

ATTRIBUTES OF PROSOPIS JULIFLORA IN AND AROUND ALLIDEGHI WILDLIFE RESERVE

Summary

This study was conducted to assess varied aspects of Prosopis juliflora in and around the Allideghi Wildlife Reserve (AWR). A combination of key informant interviews and focus group discussions was conducted to investigate the history of introduction and dispersal, as well as the awareness and attitudes of local communities towards management issues for this species. Presence or absence of P. juliflora was mapped on two-minute grid cells to determine the extent of dispersal and establishment on the Allideghi Plain. The soil seed bank was also assessed from a total of 170 soil samples collected at a five-cm depth from 30 x 30 cm quadrats across stratified sites (corrals, livestock trails, Prosopis stands, grazed grasslands, and an ungrazed control area). The effect of three growth stages of P. juliflora [small (<1 m), medium (1-3 m), and large (>3 m)] on herbaceous vegetation was investigated in a space-for-time substitution. Species composition, basal cover, litter cover, and bare ground were estimated from 30 randomly selected 20 x 50 cm quadrats using a modified Daubenmire cover scale.

Prosopis juliflora was introduced to the Ethiopian Rift Valley in the 1970s and later planted in degraded areas via government programs in 1986 and 1988. It was later dispersed to the grazing lands around the Awash River and to the Allideghi Plain by 1995. Initially, it was a widely accepted plant because of its use as shade tree, source of
fuel wood, supplemental forage, and other uses. The attitudes of Afar pastoralists to the species have changed through time, however, as its negative impacts on grazing lands, livestock, and people became more clear. For people living in towns, *P. juliflora* is still an important source of income from charcoal and firewood selling in addition to the uses mentioned above, even though they all are aware of its negative ecological impacts on grazing lands, cultivated areas, and livestock production.

"Management through utilization" is underway to control the spread of *P. juliflora*. The two major activities undertaken include charcoal production and pod grinding for livestock feed. Associations of local communities and private investors have been involved in tree harvest for charcoal production following a protocol to exploit the tree and restore grazing areas or convert invaded areas for other purposes such as cultivation. However, the strategy does not seem to be working as planned due to lack of effective implementation of the protocol. For example, plants are typically not killed when harvested for charcoal and regenerate with more stems. Pod grinding can be an effective strategy if more grinding machines are made available.

Distribution of *P. juliflora* at the Allideghi Plain mostly follows the patterns of human settlement, livestock trails, and other areas that are heavily grazed or otherwise disturbed. Distribution of *P. juliflora* revealed from field surveys indicate that more than half of the grassland is currently at risk of invasion as the plant has been widely dispersed via livestock activity. Results from the seed bank study indicate that 98% of the seeds recovered were from corrals, while only a trace amount of seeds were found under mature stands of *P. juliflora* and in the open grasslands.
Studies of herbaceous plant communities showed that all three growing stages of *P. juliflora* significantly reduce species richness and basal cover, and changed species composition, of the herbaceous vegetation compared to that of adjacent control areas. The large and medium size classes of *P. juliflora* reduced herbaceous cover by about 90% compared with the controls. The relative composition of herbaceous vegetation at control plots and under small *P. juliflora* stands was dominated by grass (86 to 87%) with the remainder forbs. Under large and medium stands, however, the composition of forbs was 65% and 56%, respectively. The number of species also decreased by 34%, 47%, and 62% along the size-class gradient compared with that of control areas. Considering the grass species, *S. ioclades* occurred under all size classes of *P. juliflora*.

**Introduction**

During the past few centuries, many plants have extended their distribution through different human activities (El-Keblawy and Al-Rawai 2007). Worldwide, woody species are increasing within arid and semi-arid grasslands, especially given the introduction of exotic species (Golubiewski 2007). Alien invasive species including those used in commercial forestry and agro-forestry cause major problems as invaders in natural and semi-natural ecosystems (Richardson 1998). In the grasslands of Africa, there is a growing concern about alien invasive species and the threats they pose to livelihoods, biodiversity and water supplies (Mwangi and Swallow 2005).

Hundreds of alien invasive tree species have been widely planted for many purposes since the second half of the twentieth century (Richardson 1998). In some cases afforestation with *Prosopis juliflora* has improved the physical and chemical properties of highly degraded sodic soils (Bhojvaid et al. 1996). Even though alien invasive trees
and shrubs contribute significantly to the economies of many countries, there are also important costs associated with their spread (Richardson 1998).

The arid and semi-arid rangelands in eastern Ethiopia are also subjected to different human and natural impacts (Gemedo-Dalle et al. 2006). Especially, encroachment of rangelands by weeds and undesirable woody plants such as *Xanthium spinosum*, *Parthenium hystophorus*, *P. juliflora*, *Acacia mellifera*, *A. nubica*, and succulents such as *Opuntia ficus-indica* have become a threat to pastoral production systems (Wittenberg 2004, Gemedo-Dalle et al. 2006, Azerefegne and Abate 2007).

*Prosopis juliflora* has invaded millions of hectares of rangelands in many countries (Pasiecznik 1999). In Ethiopia, *P. juliflora* is one of the top three priority invasive species (Wittenberg 2004, Mwangi and Swallow 2005). It has been declared a noxious weed together with *P. hystrophorus* and *Eichhornia crassipes* (Wittenberg 2004, Azerefegne and Abate 2007). The encroachment of rangelands by undesirable species is increasing and these species are responsible for a significant reduction in the production potential of rangelands (Fagg and Stewart 2002, Gemedo-Dalle et al. 2006).

*Prosopis juliflora* was reportedly introduced in the Middle Awash Valley Basin in the 1970s to serve as a shade tree and wind break for plantations (Shiferaw et al. 2004). It has aggressively invaded roadsides, grazing lands and agricultural areas forming impenetrable thickets with associated impacts on human economic activities (Azerefegne and Abate 2007). It was planted over large areas by various projects until 1982 and this continued in food-for-work relief programs from 1986 to 1988. Some planting still continues in the Tigray Region (Sertse and Pasiecznik 2005). *Prosopis juliflora* is aggressively invading pastoral areas in the Middle and Upper Awash Basin and Eastern
Hararge (Mwangi and Swallow 2005). Allideghi Wildlife Reserve (AWR), which harbors the endangered Grevy’s Zebra and other important wild animals, is currently exposed to this invasive species. Reports indicate that *P. juliflora* is also a threat for Awash National Park, which is about 40 km from a highly invaded plantation area in Amibara District (Kebede 2001, Wittenberg 2004).

An important dispersal avenue for *P. juliflora* is via livestock and other herbivores. The seeds of *P. juliflora* have hard seed coats and create a physical dormancy, which can be broken naturally by passing through the digestive system of animals (Pasiecznik et al. 1998, Shiferaw et al. 2004, El-Keblawy and Al-Rawai 2006). Dispersal and successful germination of the seeds of *P. juliflora* is mainly through the process of endozoochory, the dispersal of seeds through animal ingestion. Seeds are subsequently defecated away from the parent plant (El-Keblawy and Al-Rawai 2006, FAO 2006).

*Prosopis juliflora* is fast growing, tolerates extreme drought and salinity, serves as animal fodder, and is a good source of fuel and timber (Fagg and Stewart 2002, Pasiecznik et al. 2004, Mahgoub et al. 2005). In arid and semi-arid ecosystems, researchers have reported the positive ecological effect of *P. juliflora* such as increasing soil organic matter and nitrogen content, and prevention of soil erosion (Shiferaw et al. 2004, Herrera-Arreola et al. 2007). However, as the advantages of this plant are numerous, it also has many disadvantages. One of the major impacts is its suppression and elimination of more nutritive browse and undergrowth by competing with native species (Piguet 2001, 2003). Refer to Appendix Table 1.1 for a detailed list of plant species.
Introduction of *P. juliflora* to the Allideghi Plain is relatively recent compared with the wet season grazing sites in the district of Amibara. However, considering the importance of the plain both as a wildlife habitat and forage resource for many livestock, and the aggressive nature of *P. juliflora*, its introduction has created a great concern for conservationists and local communities, as will be shown.

**Objectives, Hypotheses, and Predictions**

**Objectives**

This study was designed with three main objectives:

i. To determine the awareness and attitudes of the local communities towards *P. juliflora* and whether the management activities which are underway are realistically pursued by local people to assist in the control of this species.

ii. To determine the dispersal of seeds in the soil and establishment of *P. juliflora* plants on the Allideghi Plain.

iii. To determine the ecological impacts of *P. juliflora* stands on the herbaceous understory in terms of basal cover, species composition, and species richness at Allideghi Plain.

**Hypotheses and Predictions**

HI: There is a positive association among the distribution of *P. juliflora* seed in the soil, establishment of the plant, and the spatial resource use patterns of livestock.

P1: Areas which are intensively used by livestock will have relatively more seeds and established stands.
H2: *Prosopis juliflora* has a negative effect on basal cover, species composition, and species richness of the herbaceous understory.

P2: These effects will be more pronounced in older stands relative to younger stands or the adjacent control sites.

**Materials and Methods**

*History, Awareness, Attitudes, and Management*

It is important to understand the interaction of both ecological and social processes in the management of rangelands (Sayre 2004). According to Sayre (2004), qualitative methods are necessary to understand the social, historical, political, and economic factors which have not been adequately covered otherwise. Qualitative research helps answer questions by examining social settings and the individuals who inhabit these settings (Berg 2004). Qualitative methods are normally important to describe the attitudes, knowledge, and behaviors of people (Margoluis and Salafsky 1998) which are unquantifiable facts (Berg 2004).

Focus group discussion is a special qualitative research technique that helps to collect data through group interactions on a specific topic (Neuman 2003). Bringing together a group of people properly in a focus group discussion takes advantage of group dynamics, increases the level of depth on key issues, increases expressiveness among members, and allows new and valuable thoughts to emerge (Margoluis and Salafsky 1998, Neuman 2003). In this study, focus group discussions with the Afar pastoralists and the town people were conducted separately because of the differences in their livelihoods. Key informant interview is also very useful to get insights quickly and inexpensively into
a particular subject such as attitudes and opinions (Margoluis and Salafsky 1998). It is important to identify a range of key informants who can provide useful perspectives of the issues (Neuman 2003).

In this study, a combination of key informant interviews, focus group discussions, and informal interviews or discussions were conducted to supplement the ecological data collected on the impact of the alien invasive *P. juliflora*. Most conservation and development projects require integrating different monitoring methods to collect both biological and social data (Margoluis and Salafsky 1998).

Focus group discussions were conducted at the local level with elders of Allideghi, Udla Issae, and Sheleko villages, the urban dwellers of the Melka Sedi and Melka Werer towns and members of three charcoal-production associations (Sidhafaghe, Serkemo, and Allideghi). These categories of people were selected based on use or knowledge of *P. juliflora*. Key informant interviews were also conducted with the respective bureau heads and experts at local, regional and federal levels. The main issues covered concerned current practices and future plans for management of *P. juliflora*. Interviews were also held with representatives and experts of the Melka Werer Agricultural Research Center, FARM Africa, and CARE about research and control programs they are conducting and their future plans to manage *P. juliflora*. The general approach in designing the questions for key informant interview and focus group discussions (Appendix A, 4.2) followed Margoluis and Salafsky (1998). In most cases a translator was used to converse in the local language called *Afar-aff*. 
Patterns of Establishment. A preliminary ground survey was conducted to map patterns of *P. juliflora* dispersal and establishment using a Global Positioning System (GPS). Data collection primarily consisted of presence/absence records in two minute (2’) grid cells (3.66 x 3.66 km) in the accessible areas of the Allideghi Plain during the 2005/06 wildlife survey (see Chapter 2). The areas are between 9° 8’N and 9° 30’ N latitude and between 40° 10’ and 40° 30’ E longitude. This area is comprised of the core grasslands that were accessible by vehicle.

During the seasonal driving survey for livestock and wildlife, GPS locations were taken for each observation of *Prosopis* seedlings, saplings, individual mature plants, and stands. All GPS readings were mapped on a GIS template as presence/absence on the grid cells.

Soil Seed Bank. Soil seed banks were another important indicator of the potential plant dispersal. Soil seed banks and patterns of seedling emergence were characterized following procedures of Pugnaire and Lazaro (2000). The soil seed bank was assessed by stratifying the study area into five categories: (1) corrals/watering sites where livestock spend the night; (2) livestock trails; (3) mature *Prosopis* stands; (4) open grazing land, and (5) the ELFORA holding ground (control).

Two sites were selected from category one to three, and 10 grid cells (sites) were selected from category four as replicates. There was only one site (ELFORA) which
served as a control. Ten points were selected on a restricted random basis from each of the sites and a five cm layer of top soil sample was taken from a 30 x 30 cm quadrat (Figure 4.1). In total, 170 soil samples were collected to determine the dispersal of *P. juliflora* seeds.

Each soil sample was sieved using a 2-mm screen and seeds of *P. juliflora* were counted. The mean density of seeds per 900 cm$^3$ of topsoil was calculated for each of the five site categories. In addition, the presence of *Prosopis* seeds was mapped on the grid cells.

**Impact on Herbaceous Vegetation**

The impact of *P. juliflora* on herbaceous vegetation (cover, species composition, species richness, and frequency of occurrence) was determined. Data were collected in October, 2005, following the main rainy season. This was the time when herbaceous species could be most readily identified at AWR.

Three different size categories (growth stages) of *Prosopis* stands, oriented around age and/or height, were identified systematically based on a preliminary reconnaissance survey and information from key informants. The size of *P. juliflora* was categorized based on their average height into small (<1 m), medium (1–3 m) and large classes (> 3 m). Three stands of *P. juliflora*, representing each of the three size classes, were selected from areas relatively distant from livestock activity to reduce the problem of foraging effects complicating data interpretation.
In each stand, a 200-m transect was laid out. The basal cover of each herbaceous species, bare ground, and litter was determined following Daubenmire (1959). Cover was estimated from 30 randomly located 20 x 50 cm quadrats along the transect. However, unlike Daubenmire who used canopy cover, basal cover was used in this study to estimate the attributes of herbaceous vegetation as it is more stable from year to year and changes less due to climatic fluctuations or other perturbations (Bonham 1989). In addition, basal cover has often been used to evaluate grasses and forbs, while canopy cover is more commonly used for woody plants (Cook 1989). Slight modification was also made in assigning cover classes [seven classes used here rather than six classes in Daubenmire (1959)] since there were species with very little cover (< 1%). The cover scale used in this study is as follows: 1 = 0-1% cover (e.g., present), 2 = 2-5%, 3 = 6-25%, 4 = 26-50%, 5 = 51-75%, 6 = 76-95%, and 7= 95-100%. The control transects were laid inside the 2,000 ha ELFORA exclosure which is an adjacent area without P. juliflora.

The design of this study included three treatments with three replicates per treatment. The three growth stages were used in a space-for-time substitution (Pickett 1989) to determine the progressive impacts of each stage of colonization of P. juliflora on total herbaceous cover, species composition, bare ground, and herbaceous species richness/diversity. Data were summarized following the procedure of Dabemire (1959). Details with respect to response variables are reviewed as follows.

Basal Cover. Vegetation cover is defined by Bonham (1989) as the percentage of ground surface covered by vegetational material. Cover is one of the most widely used measures of abundance for plant species (Floyd and Anderson 1987). Plant cover values
are used to describe plant communities by individual species and their interactions with the environment, and to monitor the effects of changes on plant species in the community (Bonham et al. 2004). Cover estimation is more time efficient (Daubenmire 1959) and is not biased by the size or distribution of individual plants (Floyd and Anderson 1987). It can be used as a basis for comparison among plants of differing life forms (e.g., grasses, forbs, shrubs) in a non-destructive manner (Cook 1986, Bonham 1989).

Basal cover is an outline of a plant near the ground surface (the area of a plant at the ground surface; Bonham 1989). According to Bonham (1989), basal area measurements have practical application on permanent plots to monitor vegetation changes through time. However, the aim of this study was to estimate the changes in basal cover of herbaceous vegetation (including bare ground and leaf litter) and determine the changes over time using space-for-time substitution.

In this study, transects with multiple quadrats were considered as sampling units for analysis to determine the differences in the attributes of the herbaceous vegetation under the three size classes of P. juliflora and the control. Thus, all the basal cover data were summarized using the midpoints of the cover classes for each species in each transect as indicated below (Table 4.1). Percent basal cover of each species was obtained by multiplying the number of quadrats in each of the seven cover classes with the midpoint of the appropriate cover class for each species and then dividing the sum of all cover classes by species by the total number of quadrats sampled on the transect (Eqn. 4.1).
Species Composition. Species composition is measured as the contribution of each species to the total vegetation cover of a plant community (Bonham 1989). Changes in species composition provide a measure of ecologically relevant changes in the environment (Philippi et al. 1998).

In this study, species composition was determined from the relative basal cover of each species by dividing the percent basal cover of each species by the total basal cover of the species. Species composition is the proportional contribution of each plant species’ cover to the total vegetation cover (Eqn. 4.2). It can be expressed by either individual species level or by species groups (i.e., annuals, perennials, grasses, forbs). In this study, the relative contribution of grasses and forbs (functional groups) to the herbaceous vegetation in the community was recorded.

\[
\text{Contribution of Sp. } A = \frac{\text{Percent cover of species } A}{\text{Total cover of all plant species}}
\]  
(Eqn 4.2)

Frequency of Occurrence. Frequency of occurrence of plants is helpful to express the spatial distribution of species across the landscape (Alhamad 2006). The percent frequency occurrence of each species was obtained by dividing the number of quadrats in which a species was observed by the total number of quadrats sampled along the transect and multiplying the resulting values by 100 (Eqn. 4.3).
Species Diversity. Diversity of the herbaceous vegetation was calculated using three indices: richness (S), heterogeneity (H), and evenness (EH) estimated by the Shannon-Wiener formula (Buttolph and Coppock 2004). Cover values can also be used to calculate diversity indices for plant communities (Bonham et al. 2004).

Species richness (S) is defined as the total number of species occurring per unit area (Alhamad 2006). In this study, species richness was estimated from the total number of species compiled along transects from 30 Daubenmire quadrats. The Shannon-Weiner Diversity Index (H) is an index that is commonly used to characterize species diversity in a community. It is a measurement used to compare diversity between habitat samples. It is calculated using the following formula (Shannon 1948):

\[
H = - \sum_{i=1}^{S} p_i \ln(p_i) \quad (Eqn. 4.4)
\]

where \(H\) is Shannon’s Diversity Index,

\(S\) is the total number of species \(i\) (richness),

\(p_i\) is the proportion of \(S\) made up of the \(i\)th species cover, and

\(\ln(p_i)\) is the natural logarithm of the proportion of the \(i\)th species.

The other Shannon measurement is Shannon's equitability (evenness) which may be referred to as homogeneity or relative diversity (Zar 1999). Evenness (EH) was calculated using the following formula:
\[ E_H = \frac{H}{H_{\text{max}}} \]  

(Eqn. 4.5)

where \( H_{\text{max}} \) = natural log of \( S \)

Evenness assumes a value between 0 and 1; if the evenness value is 1 the species are equally present in the habitat (complete evenness). Thus, according to Zar (1999), \( 1 - E_H \) may be viewed as a measure of species heterogeneity or dominance.

**Statistical Analysis**

Basal cover of species, litter and bare ground cover, species richness, and species composition were analyzed using the R Statistical Package (R 2.5.1) with a Linear Mixed-Effect model (LME). The impacts of the different size classes of *P. juliflora* on species richness, composition, and basal cover were assessed using one-way Analysis of Variance (ANOVA). The relative impact of the different size classes of *P. juliflora* on grasses and forbs (functional groups) was also determined in terms of plant cover, species richness, and species composition using one-way ANOVA. Tukey's HSD (Honestly Significant Differences) test was used to determine the least significant differences among means.

**Results**

*History, Awareness, Attitudes, and Management*

A total of eight focus group discussions were held. In addition, informal discussions were carried out with various individuals from the local communities. There was an average of seven people per focus group (Plate 4.1). In addition, thirteen formal,
key informant interviews were conducted with the respective bureau heads and experts at local (kebele and district), regional, and federal levels, as well as representative of other institutions in the area. Thus, the information in this section has been synthesized from all the focus group and key informant interviews into one overall picture. For a review of questions, see Appendix A.

History of Introduction and Dispersal. *Prosopis juliflora* is known by different vernacular names in different locations. These names may reflect the time period of initial invasion or dispersal. Around the Gewane area, for example, it is called *Dergi-Hara*, which means “tree of the Derg Regime”. The Derg Regime ruled Ethiopia under a socialist ideology from 1978 to 1991. In most of the other locations it is called “*Woyane*.” The name *Woyane* was given to this plant by the local communities because its rapid invasion of the area occurred during the establishment of the present government (1991) which was lead by Tigrayan People’s Liberation Front (TPLF). The TPLF is more commonly known as “*Woyane*” or rebels. So, in general, this suggests that *P. juliflora* was perceived as significant by locals in the period of 1978 to 1991. Also, the local names imply a negative connotation as it is aggressively invading the grazing lands.

From all the interviews and focus group discussions, it was not possible to find a consensus concerning the exact time and place of introduction for *P. juliflora*, either in the study area or generally in the region. Discussants commonly believe that it was introduced intentionally by a foreigner who worked at the cotton plantation at Melka Werer and became established in his compound residence. The Afar pastoralists believe *P. juliflora* was introduced around 1987 and it began to spread aggressively by 1991. Town people said it was introduced in the region before 1980, and some noted that they
saw some trees around the town of Gewane in 1978. One man from Melka Sedi confirmed that he brought seeds from a town called Bordede in Oromiya Region in 1981 for the first time, but there were already some trees established in nearby towns (Melka Werer and Gewane) before 1980. Therefore, the time of introduction of *P. juliflora* in the Amibara District is perceived to be no earlier than the 1970s.

After 1980, people working at the cotton plantation started to grow *P. juliflora* in their compounds and at the plantation offices in both Melka Sedi and Melka Werer. According to FARM Africa (2006), seedlings were also distributed to the people by the government in the towns between 1986 and 1988 and it was planted on large areas through a food-for-work program for the purpose of soil conservation in the district.

The main reasons to justify the introduction of this plant by individuals and government included its greenness and ability to thrive in a marginal environment. Thus, planting the trees at very hot and windy sites such as Melka Werer and Melka Seddi, where there is shortage of woody species cover, was seen to provide windbreaks, shade, wood for construction, and firewood.

In their compounds, people provided the seedlings with water. It was mentioned that the plants could set seed after about 1.5 years of age. Sheep and goats were the first to eat the pods, and they began to distribute seeds to other sites when they went to forage or water. Around 1990 and 1991, *P. juliflora* became widely distributed in Amibara District as a result of dispersal by animals and purposeful planting by people. As noted by many, there was a clear view across wide-open areas such as Amibara, Adebtole (Berta), and Melka Sedi before the introduction of *P. juliflora*. There were few native woody trees
(Acacia, Salvadora spp) on the grassland. Now such areas are reportedly covered with P. juliflora.

Around 1992, some town dwellers started to make charcoal from the mature trees in their compounds. The charcoal production has been encouraging. For instance, one respondent noted that he obtained 24 sacks of charcoal from 11 trees in 1992, which is about 10 years after germination. People began to appreciate its multipurpose uses (i.e., shade, supplemental forage, charcoal, firewood, source of income, and windbreaks). The species further dispersed in the natural environments, especially on wetter areas of the Awash River banks and irrigation channels for the plantations. This reportedly occurred mostly from the droppings of animals.

It is important to mention that before the establishment of the plantations in Amibara District, the pastoralists used Melka Werer and Melka Sedi areas as dry-season grazing lands and the Allideghi Plain as wet-season grazing land. However, this pattern has been disrupted by the establishment of plantations on the dry-season grazing areas. The Afar pastoralists are now allowed to access these areas only after cotton is harvested. Pastoral herds can graze the cotton stalks on fallow fields for about one month a year (December/January). The different Afar clans share fallow fields based on their previous customary use. Development of large-scale agricultural schemes, and hence the resulting shortage of dry-season grazing lead to establishment of permanent pastoral settlements on the Allideghi Plains (Chapter 2).

According to the people, P. juliflora was introduced to the Allideghi Wildlife Reserve (AWR) about 10 years ago (1997). As more land became occupied by P. juliflora in the dry-season grazing areas, more people started to settle permanently at the
Allideghi Plain. Currently, areas around four settlements at the AWR are heavily affected by *P. juliflora*. As mentioned above, Allideghi is serving as wet-season grazing land for livestock across Amibara District. Many livestock from highly infested areas now come and settle at the Allideghi Plain, at least temporarily, twice a year. At the same time, those pastoralists who are permanently settled at Allideghi take their animals to the plantations once a year to forage on the cotton fallow fields, where the margins are infested with *P. juliflora*. Thus, in all areas at Allideghi with some kind of settlement, either temporary or permanent, there are now *P. juliflora* stands that appear to be at different stages of growth depending on how long people and livestock have used the location (A. Kebede, personal observation).

Some local people think there are two kinds of *Prosopis* depending on the color of the leaves and size of the thorns. People at Allideghi and Udla Issae recognized that compared to plants elsewhere, the *P. juliflora* growing at the Allideghi Plain is shorter and smaller in size, lighter in color, and most of the mature trees or shrubs do not regularly set seed. However, some people felt the difference in leaf color and other features are the result of the availability of ground water. *Prosopis* trees growing in drier areas such as Allideghi are reportedly shorter and paler in color, where as those growing around the edge of rivers and irrigation channels are reportedly taller with darker green leaves.

Finally, it is clear for all the discussants and interviewees that passage of the seeds of *P. juliflora* through the digestive systems of animals facilitates dispersal and germination. According to the people, warthogs, Soemmering’s gazelle, gerenuk, oryx,
vervet monkeys, baboons, and ostriches also feed on the seeds of *P. juliflora* and have made their contributions in spreading this species in wildlife habitats.

**Attitudes of Local Communities.** *Prosopis juliflora* was first very much liked by the people. Since its introduction in home gardens and for about six to eight years after its dispersal in the natural ecosystems, people regarded it is an important multipurpose tree. People were reportedly collecting seeds from home gardens and feeding their livestock, especially sheep, goats, and calves.

The Afar pastoralists considered *P. juliflora* as an alternative forage for their livestock after observing that their animals avidly fed on the pods. As more Afar became aware of the forage value, they preferred to take their livestock to infested sites, especially when conflicts with the Issa pastoralists limited other forage options. Around 1991, *P. juliflora* began to spread to most dry-season grazing lands and the pastoralists started to change their attitudes. They recognized that this plant is not ultimately beneficial as forage grasses started to disappear from the invaded areas. As valuable forage grasses disappeared, the dependency of livestock on seeds and leaves of *P. juliflora* reportedly increased. Then, the pastoralists noticed an increase in twisted-head disease (*Cara torta*) and diarrhea in some animals that consumed large quantities of *P. juliflora* and mortality occurred. They also realized the dispersal mechanism via the droppings of their livestock to virgin foraging areas.

Some individuals have taken the lead to try some practices to improve utilization and attempt to control *P. juliflora*. Some people fed ground seeds to calves that stayed at home when forage was scarce and could not accompany their mothers to distant grazing. The calves were provided with water three times a day in addition to the milk they were
getting from their mothers twice a day. The conclusion of the herders was that if the crushed pods of *Prosopis* are offered in small amounts with enough water, especially if it is given together with grass, it can be very important as a supplement to help the animals gain weight during dry seasons.

Overall, all Afar respondents felt that the disadvantages of *P. juliflora* outweigh its advantages. The Afars are more concerned about the disadvantages which include destruction of the grasslands (eliminating the forage), killing livestock, and injuries to livestock (from the long thorns and spines). The advantages include serving as a source of income through sales of charcoal and firewood, and use for fencing. Benefits can also be complex. For example, even though it seems that people are benefiting from charcoal sales, there are reportedly conflicts among the communities on the issue of sharing sites that have been infested with *P. juliflora*.

As to other effects of this plant on the people, there are reports of injury. One Afar lost his eye from the spines when making fences and there are many reported incidents of the spines seriously injuring humans. Thick forests created by *P. juliflora* have blocked livestock from drinking points and serve as cover for predators such as hyenas or lion.

On the contrary, *P. juliflora* is still regarded as a useful plant for many town dwellers who don’t have many livestock like the Afars. Even though town dwellers have acknowledged its various negative impacts for livestock and agriculture, they still consider it an important plant in terms of wind protection, shade, charcoal making, and firewood. Those town people who are not primarily dependent on livestock herding and work for the plantation farms have also lost livestock (primarily sheep or goats) from the few they have because of *P. juliflora*. 
People who were involved in the early days of charcoal production call the plant “walelign” which means “benefited me” since they have financially benefited from it. The only other issue the town people complained about is that the stem is not strong and durable enough for building houses. At the same time, it is also reportedly competitive with other native trees which serve important roles in building houses. Even though the town dwellers said this plant should be eradicated, for them the advantages outweigh the disadvantages as they are not primarily livestock herders. However, they fear that if the present invasion continues, farming areas will also be endangered.

Management Practices. In general, it is clear for all respondents that *P. juliflora* has net negative impacts overall. However, both local and regional governmental offices haven't done research to determine the impacts of the species or its rate of dispersal. Considering the advantages and disadvantages of the plant, the idea of “management through utilization" is widely accepted at all levels, and is being employed as a control mechanism and the basis for developing management plans. A pastoral development project which includes *Prosopis* clearance, among other things, was introduced by FARM Africa in two districts of the Afar Region including Amibara District in 1998 (FARM Africa 2006). However, the implementation of the project was halted because of drought that occurred in 2002-2003. FARM Africa was forced to respond to the drought emergency and was only able to begin to implement the *Prosopis*-clearing project in 2004.

Therefore, FARM Africa is helping local communities conduct various activities to implement management through utilization. Possible control activities include stump burning, charcoal production, and pod grinding. It has been determined that stump
burning is not an effective way to kill the plant. Charcoal production and pod grinding reportedly have much better prospects. Charcoal-producing associations were established with the help of FARM Africa who developed protocols for members of the associations during and after charcoal production. The protocol (FARM Africa 2006) includes: cut all ages of *P. juliflora* at 20 cm below the ground, and leave the native woody species untouched. The people were also advised to put used engine oil on the stump after cutting the tree. Members should revisit the cleared area frequently to cut new seedlings and eventually convert the site to forage production or cropland (cotton, vegetables, etc).

In the Afar region there are now 12 associations legally established for charcoal production, and at least 30 others which do not have legal permit from the regional authorities. At Amibara, two associations were legally established in 2004 with the help of FARM Africa and district officials. In 2006, people at Allideghi also organized themselves and established a similar association. FARM Africa gave the first two associations training, tools, and initial capital and membership increased after observing the economic benefits.

Members of the associations reportedly use *P. juliflora* that are 2.5 to 3 years old for charcoal. The members produce the charcoal themselves individually or hire others to produce and sell it to the associations. The associations collect thousands of sacks of charcoal and sell it at Nazareth (Adama) or Addis Ababa using their permit to pass the natural-resource check points on the roadway. Besides the money the members get from selling the charcoal to the association, they also get money annually from profits the association has made.
Charcoal production is now one of the big businesses in the region and there are many people applying for permits. Associations formed without the knowledge of the regional government use forged documents and pass permits. This helps them gain access to infested land and pass check points to sell the charcoal “legally.” In addition, about five private investors lease lands infested with *P. juliflora* in Amibara District for future cultivation. They were automatically allowed to clear *Prosopis* by making charcoal. However, the local authority has found out that these investors abandoned the land after utilizing the *Prosopis*. This lack of control has also exposed the indigenous trees to be cut for charcoal production (Plate 4.2). In addition, private individuals are producing charcoal from the area and selling it at the road side along the main highway without passing check points. Other people are encouraged by the benefits that members of associations are getting and have started to organize themselves to participate in charcoal production. The idea is to maintain their traditional ownership of the land as others are moving towards their locality to utilize it for charcoal production.

Many charcoal producers are reportedly often not carefully following the FARM Africa protocols. As a result, shoddy practices primarily aimed to maximize income quickly reportedly have large impacts on increasing the spread of *P. juliflora*. For example, where plants are cut but not killed, many branches re-sprout and result in even greater *P. juliflora* cover. Some argue that the new growth is from the seed, not re-sprouting from the roots. They also said that the question of land ownership has prohibited them from transforming cleared areas to forage production or agricultural plots.
The pods of *P. juliflora* are very much desired forage by livestock. Thus, FARM Africa has provided the associations with pod-grinding mills as part of the *Prosopis* control mechanisms to yield livestock feed. Grinding destroys the seeds. The nutrients can be utilized and the problem of seed dispersal is eliminated. The first two associations in Amibara District have one grinding mill each. The Sidhafage association at Melka Sedi (who has members including Afar pastoralists as well as town dwellers) was using the grinder during the study period. However, the grinding mill has a low efficiency to increase production of ground pods and involve many interested people in the activity.

Initially, some of the Afar pastoralists were hesitant to accept the idea of management through utilization. They rather preferred other mechanisms which could eradicate *P. juliflora* completely from their dry-season grazing lands. However, they became convinced that this mechanism will help them to restore their lost grazing land while benefiting from selling charcoal. From personal observation, and from comments by some respondents, the control activity doesn’t seem to work as the plant is growing back. Many Afar pastoralists, especially those who are not involved in charcoal making are now seeking help from the federal government to eradicate this plant completely if there is any way to do so.

In addition to FARM Africa which helps organize local communities to clear the plant, CARE also had a plan to clear 150 ha of invaded areas from Amibara and Gewane Districts within two years beginning from January 2006. Local and regional authorities don’t have other major plans to control the spread of this plant except by strengthening the charcoal-making associations. The local communities have tried fire to control the
growth of this plant, but new growth emerges from unburned roots. The authorities
are not also encouraging the use of fire because of the fear that unmanaged fire can lead
to destruction of native vegetation.

*Distribution of P. Juliflora at Allideghi Plain*

Synthesized ecological results as provided in the following sections. See
Appendix D for detailed statistical analyses.

Patterns of Establishment. The Allideghi Plain was divided into 92, 3.66 X 3.66
km grid cells to map the establishment pattern of *P. juliflora*. It is important to note that
some of the grid cells around the boundary of the plain are not full size. About 76% of
the grid cells were surveyed which were accessible and safe by driving. It was also
attempted to map the perimeter of areas which were dominated by *P. juliflora* alone or in
combination with native species such as *A. Senegal* that were impenetrable with vehicle.
Preliminary findings in Figure 4.2 indicated that 53% of grid cells have *P. juliflora*.
About 16% of the study area has impenetrable thickets where at least 30% or more of the
canopy cover consists of *P. juliflora* typically around permanent settlements and in places
which are first visited by livestock coming from distant forage locations. Another 37% of
the study area has sparse cover of *P. juliflora*, ranging from small patches to a single
plant in a grid cell.

In general, the establishment follows livestock grazing patterns (Chapter 2) and is
associated with both permanent and temporary settlements. It is important to note that the
ELFORA holding ground, which has been fenced for about eight years, has some *P.
* *juliflora* plants. Areas in the northern part of the plain, where no *P. juliflora* plants were
observed, are mostly ungrazed or slightly grazed by both Issa and Afar livestock due to
their fear of each other. The unsurveyed area is most likely to have scant *P. juliflora* plants as there are no settlements nearby and it is not usually visited by many livestock, especially from the Afar side (A. Kebede, personal observation).

**Soil Seed Bank.** The number of seeds recovered and estimates of seeds per hectare from different sites are shown in Table 4.2. The numbers of seeds in corrals/watering sites were higher (p<0.0001) than those from other categories. Ninety-eight percent of the seeds recovered were from corrals and from 1.3% to 0.5% were found under mature *P. juliflora* stands and on the grasslands further from settlements, respectively, which are passed through animals. It seems that livestock drop most of the seeds at the corrals/watering sites. From the 100 soil samples collected at 10 grid cells on the open grasslands, relatively few seeds of *P. juliflora* were obtained in only a couple of places. One of the grids is an area which is intensively grazed by livestock coming to the plain temporarily during the rainy season. In general, the distribution of *P. juliflora* seeds showed that areas located further from settlements have fewer seeds in the soil, compared to that found in corrals, settlements, or watering sites.

In this study it was not possible to recover *P. juliflora* seeds from livestock trails using sampling methodology. However, there are clear indications that seeds are dispersed following livestock trails extending from the settlements (Plate 4.3). As can be seen in the previous section (pattern of establishment), there are small patches of *P. juliflora* visible inside the ELFORA holding ground, but no seeds were found in the soil. However, there are some seedlings in the ELFORA staff residential area, which is adjacent to the Allideghi settlement.
Impact on Herbaceous Vegetation

Impact on Basal Cover. Effects of *P. juliflora* on understory attributes are presented in Table 4.3. Details from the corresponding ANOVAs are shown in Table 4.6. Overall, these results revealed the sequential effects of maturing *P. juliflora* on the herbaceous community. The large and medium size classes of *P. juliflora* reduced herbaceous cover by about 90% compared with that of control sites. Although the small size class of *P. juliflora* had significantly higher herbaceous cover (46%) compared to that of the large (6%) or medium (13%) size classes, the herbaceous vegetation cover was significantly lower than that of the control (Table 4.3). Comparing grasses and forbs, the impact of *P. juliflora* on grasses significantly increased as the trees matured (Figure 4.3). However, basal cover of forbs under the mature stands of *P. juliflora* was significantly lower (p< 0.05) than that of the control.

It was predicted that the extent of bare ground would increase as *P. juliflora* matured, and this was confirmed (Table 4.3 and 4.6). However, litter cover did not show any significant effect due to maturity of *P. juliflora* due to the fact that *P. juliflora* created its own litter from leaf fall. The proportion of bare ground and litter under stands of large and medium *P. juliflora* was significantly higher than that covered by herbaceous vegetation (Figure 4.5). Even though the proportion of bare ground or litter under the stands of small *P. juliflora* appeared markedly higher than that of herbaceous vegetation cover, the difference was not significant. However, in uninvaded areas, the proportion of basal vegetation cover was significantly greater than that of bare ground or litter (p<0.05).
Impact on Species Composition. Relative composition of grasses and forbs under the three size classes of *P. juliflora* is shown in Table 4.4. Details from the corresponding ANOVA are shown in Table 4.6. The composition of herbaceous vegetation at control sites and under the small *P. juliflora* stands was dominated by grasses (86% to 87%) compared to that of forbs (13% to 14%). This proportion changed with the stand size of *P. juliflora*.

The relative proportion of grasses significantly decreased and that of forbs increased, as the size of *P. juliflora* increased (Figure 4.4). From the small amount of vegetation cover under the large and medium stands of *P. juliflora*, 65% and 56% of it was forbs, respectively. Of the eight and nine forbs growing under the large and medium stands, 89% and 77% of the composition was comprised of four dominant species, respectively: *Barleria argentina*, *Indigofera hochstetteri*, *Ocimum canum* and *Tribulus terrestris*.

In most cases, grasses were inhibited under older stands of *P. juliflora* (Table 4.4). Out of seven dominant grass species in the control sites, only one or two (*S. ioclades* and *C. ciliaris*) persisted under the large and medium stands of *P. juliflora*. All grass species, however, were found under small stands of *P. juliflora*. In control sites, *Sporobolus ioclades* and *Chrysopogon plumulosus* were dominant, and comprised 66% of grass cover. The twelve species of forbs comprised only 13% of total herbaceous cover.

Impact on Species Diversity. The growth of *P. juliflora* impacted the number of herbaceous species through time (Figure 4.6). Mean species richness of the herbaceous vegetation under large and medium sized *P. juliflora* was significantly lower than that
under small *P. juliflora* and under the control conditions (Table 4.3). The number of plant species decreased by 34%, 47% and 62% along the size class gradient compared with the control (Figure 4.6). The numbers of grass species were particularly reduced by 86% and 71% under stands of large and medium size classes of *P. juliflora*, respectively.

The Shannon diversity index for vegetation on the control sites was relatively higher (1.9) than that of under stands of large (1.6) and small (1.6). However, no strong relationship was evident in the diversity of herbaceous vegetation along the size class gradient. The species evenness under the control condition was relatively lower (0.6) than that of under the small stands (0.8; Table 4.3). This indicates that the species present under the large and medium size classes of *P. juliflora* stands have relatively equal proportion than those under the small stands and the control.

Impact on Frequency of Occurrence of Species. The relative frequency of occurrence of herbaceous species under each size class of *P. juliflora* and the control are presented in Table 4.5. *Cenchrus ciliaris, S. ioclades, O. canum* occurred more frequently in control sites. *Ocimum canum* and *L. nutnas* has also occurred frequently under small stands of *P. juliflora*. Under large stands of *P. juliflora*, *S. ioclades, B. argentia, I. hochstetteri, O. canum* had relatively high frequency of occurrence. Under the medium stands, *C. ciliaris* has more frequency of occurrence than the other species. *Sporobolus ioclades* had more than 15% frequency of occurrence under all size classes of *P. juliflora*.

Discussion

The focus of this chapter is on different issues concerning *P. juliflora* including attitudes and awareness of local communities, management practices, dispersal, and its
impacts on the herbaceous vegetation. Thus, interpretation of the results of these issues is carried out separately.

Attitudes and Management

*Prosopis juliflora* was introduced to the district of Amibara as a garden plant and later planted in large degraded areas within 10 years following its introduction. It then spread to agricultural areas and natural habitats and started to establish on wet grazing lands of Amibara and Gewane districts (Piguet 2003, 2001) before it was introduced to the dry season grazing lands of the Allideghi Plain by 1995. Harding and Bate (1991) indicated that river banks and depressions are suitable habitats for *Prosopis* to successfully invade arid environments.

During the first few years, *P. juliflora* was a widely accepted plant because of its uses as shade tree, source of fuel wood, supplement forage, and other potential uses. However, the attitudes of Afar pastoralist has changed through time as its impact on their grazing lands became obvious, killed their animals and spines harm themselves. For the majority of Afar people who are practicing transhumant pastoralism (Ame 2004), encroachment of *P. juliflora* in their grazing lands has become an additional problem for livestock production and health (Anon. 2002). The people have also reported the incidents of livestock death which were fed solely on pods. The cause of the death might be due to the high sugar content of the pods which weaken bacterial cellulase activity in the rumen (Pasiecznik et al. 2001). The people also reported symptoms similar to twisted head disease. Figueiredo et al (1996) also reported a similar case in Brazil.

Similarly, in Kenya, people initially appreciated *P. juliflora* due to its ability to grow in arid areas where other plants do not grow. However, their attitude has changed
when it forms impenetrable thickets, because of its negative impacts on animal and human health, and the difficulty of control (Andersson 2005). Thus, like the Afar people, local residents in invaded areas of Kenya are calling for its eradication (Aboud et al. 2005, Jama and Zeila 2005). On the other hand, it is still a well-received plant by town people as a source of income through firewood and charcoal sales. However, all are well aware of its negative ecological influences on grazing lands, plantations, and in terms of animal and human health.

The management strategy of harvesting the product for fuel as a way to control its spread is now underway by local communities. However, based on my observation of a year-old cleared area (Plate 4.4), it is difficult to say the strategy is working to control the spread. More stems are re-sprouting from cleared areas. The main reason might be a failure to implement the strategy effectively, as the majority of the effort is mainly focusing on the short-term benefit from income rather than on the long-term agenda of controlling the spread. Berhanu and Tesfaye (2006) found out that cutting *P. juliflora* may aggravate invasion unless repeated clearance of root below ground is undertaken. Their study also indicated that manual clearance coupled with bulldozing from the root was effective in plantation areas. Similarly, Shiferaw et al. (2004) reported that stumping trees at 10 cm below the ground eliminates the chance of resprouting of *Prosopis*. However, Richardson (1998) reported that exploitation of *P. juliflora* in eastern and central Sudan has not prevented it from becoming a major problem. This is because once it gets established, it is extremely difficult and expensive to eradicate (Jama and Zeila 2005).
As part of the control strategy program, the people were encouraged to collect and crush the pods of P. juliflora when feeding their livestock. Even though the idea was accepted by the people, there are not enough grinding machines to involve a significant number of people to affect control. Pod crushing is necessary to supplement livestock feed when native forage resources became limited during the dry season, as well as control the spread of the species. Crushing the pods of P. juliflora has dual purpose by making the protein in the seeds more available to the animals and at the same time destroying the seeds to prevent germination (Geesing et al. 2004). Otherwise, animals that feed on the whole pod break the hard seed coats during ingestion, which facilities germination and long-distance dispersal (Habit and Saavedra 1988, Pasiecznik et al. 1998, Shiferaw et al. 2004, El-Keblawy and Al-Rawai 2006).

*Distribution*

The degree of successful invasion of exotic species to new habitats is commonly influenced by the adaptability of the invader (El-Keblawy and Al-Rawai 2006). For well-adapted species such as P. juliflora, the limiting factor seems to be dispersal (Golubiewski 2007). However, P. juliflora has high nutritional quality fruits which are palatable to animals due to high digestibility and low concentrations of tannins (Pasiecznik et al. 2001), which helps the plant to disperse over long distances (Pasiecznik et al. 2001, Geesing et al. 2004). The work at Allideghi shows that 98% of the seeds recovered from top soil were found in corrals and settlements and the remaining 2% under stands of P. juliflora and on open grassland. This clearly indicates that this plant has dispersed through livestock. Shiferaw et al. (2004) found seed densities ranging
between 760 and 2833 per kg of animal droppings around Melka Werer, an area highly encroached with *P. juliflora*. Other studies show similar findings (Kneuper et al. 2003, Geesing et al. 2004).

As mentioned above, the numbers of seeds found under mature stands was less than 1% of the total seeds recovered from soil samples. Based on remarks of people in local communities and my personal observation, *P. juliflora* trees on the Allideghi Plain do not usually set seed. Thus, the low number of seeds under the mature stands of the parent material might be due to low seed production and/or due to livestock and wild animals feeding on the pods and depositing them away from parent plants. In addition, there were reportedly not many trees at the Allideghi Plain before the introduction of *P. juliflora*, except for a few *Acacia* species at the edge of the asphalt road to the West and around the base of the mountains to the East. Thus, as the flowers of *Prosopis* are insect pollinated, it could be reasonable to speculate that there might not be enough native pollinators attracted to the flowers of *P. juliflora*. Unlike my results, Shiferaw et al. (2004), working around Melka Werer, found a mean number of 1932 seeds/m² in invaded areas and the seed density decreased in less invaded zones where there were already some native trees. This present study also showed that while seeds are dispersed in the grazing lands further from settlements, the seeds are in relatively low numbers. The majority are dropped at settlements.

The distribution pattern of *P. juliflora* plants at the Allideghi Plain follows settlement, livestock trails, and frequently grazed sites where native vegetation cover has been disturbed and reduced. In such areas, *P. juliflora* became well established. The plant has also extended its distribution beyond these areas but at a relatively low density
The outcome of any introduction of invasive species mainly depends on the interaction of the characteristics of the potential invader and that of the invasible plant communities (Alpert et al. 2000, Barrat-Segretain 2005). In addition, the susceptibility of the native community to invasion and the competitive ability of invader are related to the availability of bare ground (Burke and Grime 1996).

Other studies also indicate that sparse vegetation cover and loss of perennial grasses due to grazing might facilitate recruitment of *Prosopis* species and other woody plants (Archer et al. 1988, Tiedemann and Klemmedson 2004, Andersson 2005). In addition, characteristics such as the ability to germinate and establish on a wide range of soil types and meet its requirements in all situations, to fix nitrogen starting at early stage (Habit and Saavedra 1988, Sharma and Dakshini 1998, Golubiewski 2007) to develop extensive tap and lateral roots quickly, to produce abundant and long-lived seeds, and its coppicing ability help *P. juliflora* to invade and spread in natural habitats and varying environmental conditions (Pasiecznik et al. 1998, Pasiecznik et al. 2001, Shiferaw et al. 2004, Le Houerou 2007).

**Impact on Herbaceous Vegetation**

This study indicated that all stages *P. juliflora* have significantly decreased richness, cover, species composition and frequency of occurrence of herbaceous vegetation. El-Keblawy and Al-Rawai (2007) also found lower species richness, evenness and frequency of the associated native species in plots under canopies of *P. juliflora*. The leaves of *P. juliflora* contain water-soluble allelochemicals which could inhibit seed germination and retard seedling growth of grasses (Al-Humaid and Warrag 1998).
However, it has no allelopathic effect on its own seedlings growing underneath the canopy (El-Keblawy and Al-Rawai 2007).

In tropical African savannas, indigenous savanna trees and shrubs can increase understory productivity and species diversity by adding nutrients to the system and reducing temperatures and evapotranspiration (Georgiadis 1989, Belsky 1994). However, with other tree species, the negative effects of competition from trees and understory vegetation can outweigh the positive effects of soil enrichment and improved plant water relations (Belsky 1994). Bhojvaid and Timmer (1998) and Singh et al (1991) indicated that shading from the canopy of *P. juliflora* reduces understory biomass. *Prosopis juliflora* competes with the understory vegetation for soil moisture and nutrients and this was illustrated when the productivity of the understory vegetation increased after removal of *P. juliflora* plants (Tiedemann and Klemmedson 1977).

**Conclusions**

In AWR and its surrounding area, it is clear that *P. juliflora* constitutes a significant threat to the sustainability of grasslands and associated environments. This considers the spatial and temporal movements of livestock (Chapter 2), the potential of the species to spread effectively via livestock, its negative impacts on native vegetation, and the ineffectiveness of management tactics currently underway. At Allideghi Plain, it is reasonable to speculate that about 16% of the grassland might lose its grazing value in less than 10 years. This part of the plain facing imminent encroachment needs immediate management. The other area which has some patches of young plants could be easily controlled with continuous intervention and monitoring. The seasonal movement patterns
of livestock between highly invaded and uninvaded sites in communal land system
will facilitate the spread and hence make control difficult. As more areas are encroached
with *P. juliflora*, livestock are forced to graze in increasingly limited areas. This in turn
creates favorable conditions for establishment.

References

*Prosopis* Tree: The Case of the II Chamus of Baringo District, Kenya. Research
Brief, the GL-CRSP Pastoral Risk Management Project (PARIMA).

Alhamad, M.N. 2006. Ecological and species diversity of arid Mediterranean grazing

Al-Humaid, A.I. and Warrag, M.O.A. 1998. Allelopathic effects of mesquite (*Prosopis
juliflora*) foliage on seed germination and seedling growth of Bermuda grass

Alpert, P., Bone E. and Holzapfel, C. 2000. Invasiveness, invisibility and the role of
environmental stress in the spread of non-native plants. - *Perspectives in Plant

Ame, A. 2004. Techno-institutional regimes and rangeland management in Ethiopia: The
role of information technologies in devising sustainable strategies. Presented at
The Commons in an age of global transition: Challenges, risks and opportunities,
the tenth conference of the international association for the study of common
property, August 9-13.

Andersson, S. 2005. Spread of the introduced tree species *Prosopis juliflora* (Sw.) DC in
the Lake Baringo area, Kenya. Institutionen för skoglig vegetationsekologi
Sveriges lantbruksuniversitet.

Anon. 2002. Impact assessment of community-based animal health workers in Ethiopia:
Initial experience with participatory approaches and methods in Afar and Wello.
Ethiopia Participatory Impact Assessment Team.

savanna: conversion of grassland to thorn woodland. - *Ecol. Monogr.* 58: 111–
127.


<http://www.eoearth.org/article/Woody_encroachment_in_the_southwestern_United_States>


(Leptochloa fusca) grown with mesquite (Prosopis juliflora) in a highly alkaline soil. - Field Crop. Res. 26: 45-55.


Table 4.1. Daubenmire cover classes.

<table>
<thead>
<tr>
<th>Cover</th>
<th>Range</th>
<th>Midpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>2 – 5</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>6 – 25</td>
<td>15.5</td>
</tr>
<tr>
<td>4</td>
<td>26 – 50</td>
<td>38.0</td>
</tr>
<tr>
<td>5</td>
<td>51 – 75</td>
<td>63.0</td>
</tr>
<tr>
<td>6</td>
<td>76 – 95</td>
<td>85.5</td>
</tr>
<tr>
<td>7</td>
<td>95 -100</td>
<td>97.5</td>
</tr>
</tbody>
</table>

Table 4.2. Seed densities (mean±SE) of *P. juliflora* recovered from top soil at various sites on the Allideghi Plain, Ethiopia.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Seed Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sites No./m²</td>
</tr>
<tr>
<td>Corral ²</td>
<td>122 ± 7.8</td>
</tr>
<tr>
<td>Trail ³</td>
<td>0 ± 0</td>
</tr>
<tr>
<td><em>P. juliflora</em> stands ⁴</td>
<td>2 ± 0.8</td>
</tr>
<tr>
<td>Grassland ⁵</td>
<td>1 ± 0.6</td>
</tr>
<tr>
<td>Control ⁶</td>
<td>0 ± 0</td>
</tr>
</tbody>
</table>

¹ Soil samples were collected at 5 cm depth from 30 x 30 cm plots from each site, and seeds were separated from the soil using a 2 mm screen.

² 20 samples were collected from corrals at Allideghi village (10 samples) and Udula Isae village (10 samples).

³ Twenty soil samples were collected along two trails.

⁴ Twenty soil samples were collected from two mature stands of *P. juliflora*.

⁵ A total of 100 samples were collected from randomly selected 10 grid cells.

⁶ The control is an adjacent un-invaded area (ELFORA holding ground).
Table 4.3. Summary of various attributes (mean±SE) for transects under stands of different size classes of *P. juliflora* and a control at Allideghi Wildlife Reserve, October 2005. 1, 2

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover (%) 5, 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>4.8 ± 1.12 Aa</td>
<td>10.4 ± 2.48 ABa</td>
<td>36.4 ± 10.42 Ab</td>
<td>79.0 ± 4.71 AC</td>
</tr>
<tr>
<td>Forbs</td>
<td>3.1 ± 0.67 Aa</td>
<td>5.9 ± 1.53 ABa</td>
<td>4.3 ± 0.42 ABa</td>
<td>10.1 ± 0.06 AB</td>
</tr>
<tr>
<td>Grasses</td>
<td>1.7 ± 0.45 Aa</td>
<td>4.5 ± 1.00 ABa</td>
<td>32.1 ± 10.84 Bb</td>
<td>68.9 ± 4.76 Bb</td>
</tr>
<tr>
<td>Other</td>
<td>88.9 ± 2.42 Ab</td>
<td>87.9 ± 3.30 BA</td>
<td>56.9 ± 0.97 Ab</td>
<td>42.7 ± 2.38 Ab</td>
</tr>
<tr>
<td>Litter</td>
<td>6.5 ± 0.91 Ab</td>
<td>6.6 ± 0.91 BA</td>
<td>9.5 ± 0.13 Ab</td>
<td>13.2 ± 0.52 Ab</td>
</tr>
<tr>
<td>Bare ground</td>
<td>82.4 ± 1.55 Ab</td>
<td>81.3 ± 2.41 BA</td>
<td>47.4 ± 0.96 Bb</td>
<td>29.5 ± 1.86 Sc</td>
</tr>
</tbody>
</table>

| Species richness(No.) 7 |       |        |       |         |
| Total vegetation       | 7.3 ± 0.33 | 10.3 ± 0.67 | 12.7 ± 1.20 | 19.3 ± 0.67 |
| Grass                  | 1.0 ± 0.00 Ab | 2.0 ± 0.00 Ab | 5.3 ± 0.89 Ab | 7.0 ± 0.00 Ab |
| Herb                   | 6.3 ± 0.33 Ab | 8.3 ± 0.67 Bb | 7.3 ± 0.33 Ab | 12.3 ± 0.67 Bb |

| Species Diversity (Index) 8 |       |        |       |         |
| Shannon-Wiener Index    | 1.6 ± 0.06 AC | 1.8 ± 0.08 AC | 1.6 ± 0.05 A | 1.9 ± 0.05 C |
| Evenness               | 0.8 ± 0.05 A | 0.8 ± 0.04 AB | 0.6 ± 0.02 CB | 0.6 ± 0.01 CB |

1 Basal cover data were collected from 30, 20 x 50 cm Daubenmire quadrats for each of three transects for each size classes. Data were collected in October following the main rainy season.

2 Means accompanied by the same small letters in columns, and capital letters in rows, were not significantly different (P ≥ 0.05) following Tukey’s HSD post-hoc significance test.

3 Comparisons of cover values were made between vegetation and other, forbs and grasses, and litter and bare ground, and separately for other attributes.

4 Where large is >3 m height, medium is 1-3 m, small is < 1 m, and the control is an adjacent un-invaded area.

5 Daubenmire basal cover (mean ± SE).

6 Total percentages of basal cover may differ from 100 % due to the Daubenmire mid-point estimation method used.

7 Total number of species (mean ± SE).

8 Species diversity for forb and grass species combined.
Table 4.4. Species composition (%) of herbaceous vegetation (mean±SE) under stands of different size classes of *P. juliflora* and a control at Allideghi Wildlife Reserve, October 2005. 1, 2

<table>
<thead>
<tr>
<th>Species</th>
<th>Grasses</th>
<th>Forbs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total grasses</td>
<td>Total forbs</td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Grasses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total grasses</strong></td>
<td>34.8 ± 1.66&lt;sup&gt;aA&lt;/sup&gt;</td>
<td>43.8 ± 2.27&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>Aristida adoensis</em></td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><em>Cenchrus ciliaris</em></td>
<td>---</td>
<td>13.5 ± 8.57</td>
</tr>
<tr>
<td><em>Chrysopogon plumulosus</em></td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><em>Digitaria rivae</em></td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><em>Lintonia nutans</em></td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><em>Panicum coloratum</em></td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><em>Sporobolus ioclades</em></td>
<td>34.8 ± 1.66</td>
<td>30.2 ± 7.28</td>
</tr>
<tr>
<td><strong>Forbs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total forbs</strong></td>
<td>65.2 ± 1.66&lt;sup&gt;bA&lt;/sup&gt;</td>
<td>56.2 ± 2.27&lt;sup&gt;bA&lt;/sup&gt;</td>
</tr>
<tr>
<td><em>Abutilon figarianum</em></td>
<td>0.29 ± 0.18</td>
<td>1.2 ± 0.65</td>
</tr>
<tr>
<td><em>Barleria argentia</em></td>
<td>21.5 ± 6.64</td>
<td>12.7 ± 8.19</td>
</tr>
<tr>
<td><em>Chenopodium album</em></td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Table 4. 4. cont'd

<table>
<thead>
<tr>
<th>Species list</th>
<th>Size Class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large</td>
</tr>
<tr>
<td><em>Indigofera hochstetteri</em></td>
<td>13.2 ± 1.79</td>
</tr>
<tr>
<td><em>Ipomoea sp</em></td>
<td>---</td>
</tr>
<tr>
<td><em>Jatropha lobata</em></td>
<td>0.17 ± 0.17</td>
</tr>
<tr>
<td><em>Kohautia coccinea</em></td>
<td>---</td>
</tr>
<tr>
<td><em>Leucas nubica</em></td>
<td>6.6 ± 2.83</td>
</tr>
<tr>
<td><em>Ocimum canum</em></td>
<td>13.7 ± 2.08</td>
</tr>
<tr>
<td><em>Orthosiphon pallidus</em></td>
<td>0.4 ± 0.20</td>
</tr>
<tr>
<td><em>Rhynchosia minima</em></td>
<td>---</td>
</tr>
<tr>
<td><em>Seddera bagshawei</em></td>
<td>---</td>
</tr>
<tr>
<td><em>Tribulus terrestris</em></td>
<td>9.3 ± 7.02</td>
</tr>
</tbody>
</table>

1 Basal cover data were collected from 30, 20 x 50 cm Daubenmire quadrats for each of three transects for each size class. Data were collected in October following the main rainy season.

2 Means accompanied by the same small letters in columns, and capital letters in rows, for total grasses and total forbs were not significantly different (P ≥ 0.05) following Tukey’s HSD post-hoc significance test.

3 Where large is >3 m height, medium is 1-3 m, small is < 1 m, and the control is an adjacent un-invaded area.

4 T is trace amount (< 0.1%).
Table 4.5. Percent frequency of occurrence for herbaceous species (mean±SE) under stands of different size classes of *P. juliflora* and a control at Allideghi Wildlife Reserve, October 2005.\(^1\)

<table>
<thead>
<tr>
<th>Species</th>
<th>Size Class 2</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grasses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. adoensis</em></td>
<td>---</td>
<td>---</td>
<td>5.6 ± 5.56</td>
<td>3.3 ± 3.33</td>
<td></td>
</tr>
<tr>
<td><em>C. ciliaris</em></td>
<td>---</td>
<td>31.1 ± 12.81</td>
<td>17.8 ± 9.09</td>
<td>67.8 ± 1.11</td>
<td></td>
</tr>
<tr>
<td><em>C. plumulosus</em></td>
<td>---</td>
<td>---</td>
<td>17.8 ± 17.78</td>
<td>18.9 ± 2.22</td>
<td></td>
</tr>
<tr>
<td><em>D. rivae</em></td>
<td>---</td>
<td>---</td>
<td>6.7 ± 0.00</td>
<td>13.3 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>L. nutans</em></td>
<td>---</td>
<td>---</td>
<td>48.9 ± 2.94</td>
<td>14.4 ± 5.56</td>
<td></td>
</tr>
<tr>
<td><em>P. coloratum</em></td>
<td>---</td>
<td>---</td>
<td>14.4 ± 1.11</td>
<td>13.3 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>S. ioclades</em></td>
<td>15.6 ± 1.11</td>
<td>14.4 ± 1.11</td>
<td>23.3 ± 13.33</td>
<td>57.8 ± 2.22</td>
<td></td>
</tr>
<tr>
<td><strong>Forbs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. figarianum</em></td>
<td>2.2 ± 1.11</td>
<td>11.1 ± 5.88</td>
<td>14.4 ± 1.11</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><em>B. argentia</em></td>
<td>14.4 ± 2.22</td>
<td>17.8 ± 4.86</td>
<td>5.6 ± 2.22</td>
<td>10.0 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>C. album</em></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>6.7 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>C. grandis</em></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>12.2 ± 1.11</td>
<td></td>
</tr>
<tr>
<td><em>I. hochstetteri</em></td>
<td>14.4 ± 2.22</td>
<td>22.2 ± 1.11</td>
<td>8.9 ± 2.22</td>
<td>23.3 ± 3.33</td>
<td></td>
</tr>
<tr>
<td><em>J. lobata</em></td>
<td>2.2 ± 2.22</td>
<td>5.6 ± 1.11</td>
<td>17.8 ± 2.94</td>
<td>20.0 ± 3.33</td>
<td></td>
</tr>
<tr>
<td><em>K. coccinea</em></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>10.0 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>L. nubica</em></td>
<td>5.6 ± 1.11</td>
<td>20.0 ± 7.70</td>
<td>---</td>
<td>16.7 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>O. canum</em></td>
<td>16.7 ± 5.77</td>
<td>17.8 ± 2.94</td>
<td>65.6 ± 1.11</td>
<td>52.2 ± 2.22</td>
<td></td>
</tr>
<tr>
<td><em>O. pallidus</em></td>
<td>4.4 ± 2.22</td>
<td>11.1 ± 5.56</td>
<td>2.2 ± 2.22</td>
<td>15.6 ± 4.44</td>
<td></td>
</tr>
<tr>
<td><em>R. minima</em></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>6.7 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>S. bagshawei</em></td>
<td>---</td>
<td>10.0 ± 1.92</td>
<td>7.8 ± 4.44</td>
<td>46.7 ± 0.00</td>
<td></td>
</tr>
<tr>
<td><em>T. terrestris</em></td>
<td>4.4 ± 2.22</td>
<td>8.9 ± 1.11</td>
<td>14.4 ± 1.11</td>
<td>14.4 ± 4.44</td>
<td></td>
</tr>
<tr>
<td><strong>Litter and Bare ground</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litter</td>
<td>97.8 ± 1.11</td>
<td>100 ± 0.00</td>
<td>100 ± 0.00</td>
<td>100 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Bare ground</td>
<td>100 ± 0.00</td>
<td>100 ± 0.00</td>
<td>100 ± 0.00</td>
<td>100 ± 0.00</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Data were collected from 30, 20 x 50 cm Daubenmire quadrats for each of three transects for each size class. Data were collected in October following the main rainy season.

\(^2\) Where large is >3 m height, medium is 1-3 m, small is <1 m, and the control is an adjacent un-invaded area.
Table 4.6. Analysis of variance results for the effects of size class of *P. juliflora* on various attributes of herbaceous vegetation at the Allideghi Wildlife Reserve, October 2005.¹

<table>
<thead>
<tr>
<th>Source</th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent plant cover⁴</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size class⁵</td>
<td>3</td>
<td>14</td>
<td>4.50</td>
<td>.0208</td>
</tr>
<tr>
<td>Functional group⁶</td>
<td>1</td>
<td>14</td>
<td>131.76</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Size class x Functional group</td>
<td>3</td>
<td>14</td>
<td>78.51</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Percent litter and bare ground cover⁷</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size class</td>
<td>3</td>
<td>14</td>
<td>163.99</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Litter/bare ground</td>
<td>1</td>
<td>14</td>
<td>3239.98</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Size class x Litter/bare ground</td>
<td>3</td>
<td>14</td>
<td>263.27</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Species richness⁸</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size class</td>
<td>3</td>
<td>14</td>
<td>121.76</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Functional group</td>
<td>1</td>
<td>14</td>
<td>422.12</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Size class x Functional group</td>
<td>3</td>
<td>14</td>
<td>48.63</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Species composition⁹</td>
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<td></td>
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<td></td>
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<tr>
<td>Size class</td>
<td>3</td>
<td>14</td>
<td>0.00</td>
<td>1.000</td>
</tr>
<tr>
<td>Functional group</td>
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<td>14</td>
<td>208.58</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Size class x Functional group</td>
<td>3</td>
<td>14</td>
<td>237.86</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

¹ Analysis was done on data collected from 30, 20 x 50 cm Daubenmire quadrats for each of three transects for each size class. Data were collected in October following the main rainy season.

² Numerator degree of freedom.

³ Denominator degree of freedom.

⁴, ⁷ Daubenmire basal cover values.

⁵ Where large is >3 m height, medium is 1-3 m, small is <1 m, and the control is an adjacent un-invaded area.

⁶ Grasses and forbs.

⁷ The contribution of litter and bare ground covers under the *P. juliflora* stands.

⁸ Total number of species.

⁹ The contribution of each functional group to total herbaceous cover.
Figure 4.1. Random and systematic selection of sites for soil collection to determine the dispersal of *P. juliflora* seeds at Allideghi Plain. The control (ELFORA), mature *P. juliflora* stands and the two corrals in the villages were selected systematically. 10 grassland grids were selected randomly, where SG is slightly grazed, MG is moderately grazed, and HG is highly grazed.
Figure 4.2. Distribution of *P. juliflora* on the Allideghi Plain. This was determined during the 2005/2006 field survey driving every 2 minutes, east-west or west-east. All of the mountainous areas and a few grassland areas were not surveyed because they were pastoral conflict zones.
**Figure 4.3.** Percent absolute cover of herbaceous vegetation (mean±SE) under different size classes of *P. juliflora* and in a control area at Allideghi Wildlife Reserve, October 2005. Percent cover is totaled for grasses or forbs. Basal cover was estimated using the Daubenmire method with a total of 30 quadrats across each of three transects per size class. Size classes of *P. juliflora* were defined as large (>3 m height), medium (1-3 m), small (<1 m), and the control was an adjacent un-invaded area.
Figure 4.4. Relative composition of herbaceous vegetation (mean±SE) according to functional groups (grasses and forbs) under the different size classes of *P. juliflora* and a control at Allideghi Wildlife Reserve, October 2005. Species are totaled for grasses and forbs. Basal cover was determined using the Daubenmire method with a total of 30 quadrats across each of three transects per size class. Size classes of *P. juliflora* were defined as large (>3 m height), medium (1-3 m), small (<1 m), and the control was an adjacent un-invaded area.
Figure 4.5. Percent basal cover of herbaceous vegetation and litter or bare ground (mean±SE) under different size classes of *P. juliflora* and an adjacent control at Allideghi Wildlife Reserve, October 2005. Cover was estimated using the Daubenmire method with a total of 30 quadrats across each of three transects per size class. Size classes of *P. juliflora* were defined as large (>3 m height), medium (1-3 m), small (<1 m), and the control was an adjacent un-invaded area.
Figure 4.6. Species richness (number; mean±SE) of herbaceous vegetation under different size classes of *P. juliflora* and an adjacent control at Allideghi Wildlife Reserve, October 2005. Number of species was obtained using the Daubenmire method with a total of 30 quadrats across each of three transects per size class. Size classes of *P. juliflora* were defined as large (>3 m height), medium (1-3 m), small (<1 m), and the control was an adjacent un-invaded area.
CHAPTER 5

VEGETATION CHANGE

Summary

This study concerns the Allideghi Wildlife Reserve (AWR) and surrounding areas in the district of Amibara, Afar Regional State. The main objectives were to assess changes in vegetation cover at the landscape level due to proliferation of *P. juliflora*. Three multi-temporal satellite images (MSS, TM, and ASTER) of a 3,916 km² study area taken over 32 years (1973-2005) were used for change detection and classification. The MSS and TM images were acquired on January 30th 1973 and 1986, respectively, while the ASTER images were acquired on January 1st 2005.

Standard image preprocessing operations such as geometric correction, normalization, mosaicking, and subsetting were applied before conducting change-detection analysis. Supervised classification was performed on the ASTER image to define the land-cover types of the project area. Write-function memory insertion, red and NIR band differencing, and Normalized Difference Vegetation Index (NDVI) differencing techniques were used to determine vegetation change. Analyses were performed comparing images 1973 and 1986, 1986 and 2005, and 1973 and 2005. Change in the red and NIR bands and in terms of NDVI was measured as the difference between late-date minus early-date measurements using three standard-deviation thresholds.

The results of all techniques showed that there was both an increase and a decrease in vegetation cover in different parts of the district during the two periods from
1973 to 1986 and from 1986 to 2005. The change that occurred between 1973 and 1986 was primarily a result of agricultural expansion associated with river valleys and a temporal shift in the harvest time for crops such as cotton. During the period 1986 to 2005, however, the amount of green vegetation cover increased in the riparian zone to the west and rangeland areas to the west and east. Results from all three differencing techniques were in agreement that green vegetation increased in the rangelands to the west. This change is likely related to expansion of *P. juliflora*. Despite variation in the amount of area detected by each technique, at least 15,000 ha of the district gained green vegetation cover between 1986 and 2005. Vegetation cover losses also occurred both in the rangelands and on agricultural areas during the same period.

In general, there was both land-use and land-cover changes during the past 32 years. The change in land-use was directly related with agricultural expansion. Land-cover change was due to partly shifting the composition of the natural vegetation and partly to loss of vegetation cover. The shift in composition was due to *P. juliflora* encroachment on traditional dry-season grazing areas. Loss of vegetation was partly in agricultural areas due to shift in harvest time and partly in the rangelands which might be due to overgrazing.

The study area was classified into seven cover types: grassland, *Acacia* shrubland, *P. juliflora* shrubland, water, volcanics, plantation, and open shrubland/woodland. By 2005, the cotton plantations occupied about 18,000 ha (5%) of the district. The *P. juliflora* shrubland covered about 10% of the district. Grassland, wooded grassland, and shrubland covered about 75% of the districts in total.
Introduction

World wide, reports indicate that over the past 50 to 300 years, woody species have been encroaching and changing the tree-grass matrix of arid and semi-arid rangelands; this is coincident with introductions of exotic species and/or changes in disturbance regimes (Golubiewski 2007). Exotic plant species have been intentionally introduced world wide for their economic, environmental, or aesthetic values, and/or have spread accidentally, via trade and natural dispersal (Pimentel et al. 1999). However, even the intentional introduction of new species has not always served the planned purpose; rather, many species have become invasive (Richardson 1998, Andersson 2005). During the past 40 years, the rate of invasion and risks associated with invasive species has increased enormously due to human population growth, rapid movement of people from place to place, and alteration of the environment (Pimentel et al. 1999).

Invasive species compete with native species and can exert negative economic, environmental and social impacts as well as alter ecosystem structure and functions [e.g., primary productivity, biodiversity, nutrient cycling, Vitousek and Walker (1989), Mack et al. (2000)]. Invasion of natural plant communities by non-indigenous species constitutes a major global threat to biodiversity of rangelands, along with habitat loss (Lodge 1993, Miller 2000, Palmer and Fortescue 2003). Exotic plant species that grow more rapidly and that are more competitive than native species can be dangerous (Mungroo and Tezoo 2000). Such species are threatening the biological diversity of rangelands as well as the economies supported by those ecosystems (Lawrence et al. 2006). In the United States alone, invading non-indigenous species cause major
environmental damage, including several billion dollars worth of annual losses to crops, pastures, and forests as well as costs for control (Pimentel et al. 1999).

Many factors influence the spread and success of alien invasive species including disturbance, propagule input (vectors), and climatic conditions, as well as interactions among these factors (Gou et al. 2006, Britton-Simmons and Abbott 2008). At regional scales, the spread of exotic plants is directly correlated with community richness of native species as well as the availability of transportation networks for propagules (Guo et al. 2006). For some well-adapted species such as P. glandulosa to different environmental conditions, the limiting factor seems to be dispersal (Golubiewski 2007).

The exotic and fast growing woody plant, P. juliflora was introduced to Ethiopia in 1970s and has spread in arid and semi-arid parts of the country including the district of Amibara in Afar Regional State. During the past 10 years, P. juliflora has been distributed to protected wildlife areas such as the grassland plain of the Allideghi Wildlife Reserve (AWR). As mentioned in Chapter 1, Grevy’s Zebra is currently restricted to northern Kenya and southern and central Ethiopia. The Allideghi Plain, which is situated in Amibara district, supports an isolated, northernmost population of Grevy’s Zebra, and is an important forage resource for many livestock held by the Afar pastoralists. The sustainability of the Allideghi Plain as a wildlife habitat for the future survival of a viable population of Grevy’s Zebra and other important wild animals may be primarily affected by the current expansion and impact of P. juliflora throughout the Amibara District. The management of land outside of a protected area can often be crucial to the conservation objectives within a protected area as well as to broader conservation goals within a country (Goodland et al. 1998).
In ecosystem management, sustainability has become a primary objective, which needs a continuous source of accurate and up-to-date resource data (Coppin et al. 2004). Remote sensing can provide an efficient means of recording both long-term (years or decades) and short-term (daily or seasonal) changes of ecosystems using multi-temporal digital images at various scales (Washington-Allen et al. 2006). Remote sensing is a valuable and an effective technology to detect, monitor, and manage invasive species affecting rangelands, forests, and pastures (Beyers et al. 2002, Joshi et al. 2004, Lass et al. 2005, Lawrence et al. 2006). As indicated by many investigators, satellite imagery can be used from the preparation of base maps for resource inventory to estimating the extent and severity of land cover changes in rangelands (Washington-Allen et al. 1998, 2006, Palmer and Fortescue 2003). Remote sensing data can also help to monitor the extent of invasions and assist with the planning of control and eradication programs (Palmer and Fortescue 2003). According to Goodland et al. (1998), one of the initial steps in developing an effective management program is to map the current and potential geographic range of invasive species.

Researchers have developed procedures to detect, identify, and map ecosystem changes using multi-spectral images taken at two or more times, irrespective of the cause of change (Singh 1989, Macleod and Congalton 1998, Sohl 1999, Coppin et al. 2004). Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh 1989). Change detection determines change of a particular object between two or more time periods to yield a quantitative spatial analysis in an area of interest (Macleod and Congalton 1998). The four aspects of change detection which are important when monitoring natural resources
are detecting that change has occurred, identifying the nature of the change, measuring the extent of the change, and assessing the spatial pattern of the change (Singh 1989, Macleod and Congalton 1998).

Comparison of two or more satellite images acquired at different times can be used to evaluate the temporal or spectral reflectance differences that have occurred between two dates to detect land-cover change (Masry et al. 1975, Yuan and Elvidge 1998). A land-cover change can reflect how the land has been managed, and this can be evaluated using change detection methodologies (Brothers and Fish 1978) such as write-function memory insertion, band differencing, band ratioing, differencing vegetation-index images, and post classification comparison (Singh 1989, Jensen 2005).

Thus, the main objective of this study was to determine the trends of vegetation change through time in and around the AWR due to the impact of _P. juliflora_ and other factors using remotely sensed data. Another objective was to map vegetation and other land-cover types to determine the extent of _P. juliflora_ establishment in Amibara district. Different change detection techniques such as write-function memory insertion (WFMI), image algebra (red and NIR bands and normalized difference vegetation index differencing) were used to determine the land-cover change in the district of Amibara from 1973 to 2005.

**Description of the Study Area**

The study area, Amibara District, includes the Allideghi Plain and is one of the 29 districts of the Afar Regional State of Ethiopia. It comprises 391,985 ha and is located in Administrative Zone III of the Region. Amibara District is bordered on the South by
Awash Fentale District, on the West by the Awash River (which separates it from Dulecha District to the southwest), by Administrative Zone V to the northwest, by Gewane District to the North, and extends eastwards into the Allideghi Plain bordered by Oromia Region (Figure 5.1). The district administrative office is situated at a locality called Andido, at the edge of the asphalt highway. Amibara District includes small towns such as Awash Arba, Melka Werer, Melka Sedi, Awash Sheleko and many permanent villages (settlements).

Amibara is located between 40° 06' to 40° 46' E longitudes and 8° 58' to 9° 57' N latitudes. Figure 5.1 shows the location and extent of the study area. The study area is a level plain in most cases with elevations ranging from 730 and 870 masl, with one small peak at 955 masl. The mean annual rainfall for the entire district ranges from 500-600 mm and the mean annual temperature ranges from 25-30°C (Ethiopian Government 1981).

This district has an estimated human population of 54,190 (CSA 2005), of which most are primarily dependent on livestock herding. The population is largely comprised of ethnic Afars. Non-Afars are predominantly highlanders of various ethnic groups that immigrated to work on the state farms, other government offices, and private businesses. In 1968, a large-scale irrigation project (Amibara-Melka Sedi) was introduced along the Awash River on the dry-season grazing land. In addition, during the past two decades, *P. juliflora* has rapidly invaded the traditional agro-pastoral areas, wildlife habitats, cultivated lands, and residential areas. This invasion alarmed pastoralists, wildlife managers, policy makers, development agents, and scientists (Shiferwa et al. 2004).
The AWR provides important wildlife habitat. It is dominated by a large plain and has mountains rising along the eastern border. Part of the AWR, the grassland plain (Allideghi Plain), is located in Amibara District (Figure 5.1). The mountainous part of the reserve in the east is located in Oromia Regional State. Allideghi Plain covers about one fifth of the district, 84,680 ha. *Chrysopogon plumulosus, Sporobulus ioclades,* and *Cenchrus ciliaris* comprise a relatively high percentage of herbaceous vegetation cover on the plains, with some area occupied by *Acacia senegal* along the highway. The Allideghi Plain is both a permanent grazing and settlement area for some pastoralists as well as a seasonal grazing area for many livestock of migratory Afar pastoralists during the wet season. *Prosopis juliflora* was introduced to the Allideghi Plain about 10 years ago.

**Materials and Methods**

Land cover refers to the type of natural or man-made material present on the landscape such as water, crop, forest, etc. (Jensen 2005). This study addresses vegetation/land cover change in Amibara District over 32 years from 1973 to 2005. The shift from grassland and/or open savanna to agriculture and shrubland is visually apparent in the study area. However, the focus of this study is land cover change due to *P. juliflora* encroachment.

**Data Type and Acquisition**

Three kinds of satellite data were obtained for the vegetation-change analysis. These include the Landsat Multi-Spectral Scanner (MSS), Landsat Thematic Mapper (TM), and the Advanced Space-borne Thermal Emission and Reflection Radiometer
(ASTER). It was not possible to get anniversary-date imagery of the Landsat Enhanced Thematic Mapper (ETM+) in 2000 for part of the study area. Landsat MSS and TM imagery were acquired by the National Aeronautics and Space Administration’s (NASA) global ortho-rectified Landsat data set. The satellite images were obtained free of charge from Earth Science Data Interface (ESDI), freely available through the University of Maryland's Global Land Cover Facility (GLCF) (http://www.landcover.org). The ESDI is the GLCF's web application for searching, browsing, and downloading data on line. The ASTER imagery was also obtained from the USGS EROS Center under a NASA-funded investigation agreement for the intermountain region. A summary of acquired imagery is shown in Table 5.1.

For change detection, it is important to acquire imagery of anniversary dates or within anniversary windows to minimize discrepancies in reflectance caused by seasonal vegetation fluxes and sun-angle differences (Coppin and Bauer 1994, Coppin et al. 2004). Even though selection of appropriate imagery is an important component for successful vegetation change detection, data selection was primarily driven by availability of imagery covering the study area. Efforts were made to select images which were taken on an anniversary date, or within anniversary windows or similar seasons (in this case during dry periods when vegetation would have relatively low moisture content).

The MSS and TM imagery used in this study were acquired for January 30th 1973, and January 30th, 1986, respectively (Table 5.1). The acquisition date of the ASTER data was January 1, 2005, which was also a dry and cloud-free period of the year. Thus, all of the images selected for change detection fulfilled the guidelines of Burns and Joyce
In January, all the natural vegetation (grasses, forbs and *Acacia* spp) except those along the Awash River and the other permanent water areas are dry.

The ASTER imagery constitutes the base data layer from which the current land cover maps (vegetation maps) were derived based on ground truthing. The ASTER images were used to classify land cover types of the AWR and the surrounding pastoral grazing lands. The ASTER sensor has 14 spectral bands: three in the visible and near-infrared (VNIR) wavelength regions of 15-m spatial resolution, six in the short wave and infrared (SWIR) bands of 30-m, and five in the thermal infrared (TIR) bands of 90-m pixel size. For this study, only band 1, 2 and Band 3N in the VNIR wavelengths were used because of the similarity of the spectral resolution with red and NIR bands of MSS and TM images.

The ASTER images are applicable for agriculture monitoring as well as studying vegetation and climatic change (Abrams 2000, Jinlong et al. 2003). The ASTER data used for this study are level 1b (level 1a data that have been processed to sensor units). Thus, ASTER imagery with 15-m spatial resolution was also used to determine the land cover types and especially to map the current status of *P. juliflora*. According to Aynekulu et al., (2006), ASTER imagery is also applicable for mapping land cover in other dry lands of Ethiopia.

*Vegetation Classification and Change Detection*

In order to design a management plan and allow for monitoring of rangelands, land-cover maps are very important (Cingolani et al. 2004). Land-cover maps are the basis for assessing environmental changes such as land cover or land use over a certain
period of time, especially in areas where it has a national significance for conservation of endangered species such as at AWR.

Image Preprocessing. Data from remotely sensed images obtained from different providers are not usually ready to use directly, and thus need to undergo a series of preprocessing steps. Prior to image classification and change detection, there are a series of operations which must be carried out on the multi-temporal remote sensor data: geometric correction, image registration (geo-referencing), radiometric correction (normalization), and mosaicking, subsetting, and masking unnecessary features (Jensen 2005, Galiasatos et al. 2007). The objective of preprocessing is to remove errors associated with acquisition of multi-temporal data, including atmospheric and illumination effects, and mis-registration of images acquired by different multi-spectral sensors under different atmospheric conditions (Galiasatos et al. 2007). An illustration of a processing flow chart is depicted as Figure 5.2.

Initial Processing. As shown in Table 5.1, most of the data were acquired as GeoTIFF (Geostationary Earth Orbit Tagged Image File Format) zip files. The individual band data (.tif files) were unzipped and imported to ERDAS Imagine as .img files in grey color and the bands were then stacked to create the color composite. The ASTER images were obtained as .img files. All of the pre-processing, change detection, and production of maps were performed using ERDAS Imagine 8.5 and ArcGIS 9.2 software.

Geometric Correction (Orthorectification) and Image Registration. Geometric correction addresses errors in the relative positions of pixels, which might be induced by the interaction of sensor-viewing geometry and terrain variations (ERDAS 2003, Tucker et al. 2004). It is necessary to geometrically rectify the imagery of two or more dates for
Data from Landsat MSS from the 1970s and TM from the 1990s have been geometrically adjusted and orthorectified by the GeoCover-Ortho program, sponsored under NASA’s Scientific Data Buy Program for research and education (Tucker et al. 2004). These Landsat data sets undergo common orthorectification to minimize between and among-scene registration errors in each time frame, and minimize classification errors due to mis-registration.

The Landsat TM was first orthorectified using ground-control points. A nearest-neighbor interpolation was used to calculate the spectral intensity values of the image pixels within the final orthorectified image to preserve the original spectral information. In addition, each TM reflective band was resampled using a nearest-neighbor algorithm to 28.5-m resolution pixels for the reflective bands. According to Tucker et al. (2004), the final orthorectified TM reflective channel data have a root-mean-square (RMS) geodetic accuracy of less than 50 m.

The Landsat MSS data were orthorectified and co-registered to the orthorectified TM data using the same digital elevation model data set used for TM orthorectified data. The nominal position accuracy of the MSS product is less than a RMS of 100 m. The MSS pixels were resampled to 57.0 m (twice the size of the TM). Thus, all the MSS and TM satellite imagery obtained from GLCF for this study are georegistered and orthorectified so that each Landsat image has the spatial accuracy required for quantitative land-surface studies (Tucker et al. 2004).

The ASTER images were georeferenced with the TM georeferenced image using 21 control points of identifiable features with a root mean square of 6.5 m and a first
polynomial function. Relatively few control points were used because of lack of many identifiable features in the area.

Image registration is the process of transforming the different sets of data into one coordinate system. All the GeoCover-Ortho Landsat MSS, TM and ASTER products were projected to Universal Transverse Mercator (UTM) projection on the WGS84 datum using nearest neighbor resampling. In general, all the satellite imagery and GIS data layers used in this study were registered to UTM Zone 37, WGS coordinate system.

Radiometric and Atmospheric Correction (Normalization). It is difficult to interpret true land-cover changes if they are masked by differences in atmospheric conditions between anniversary dates (Sohl 1999). Radiometric correction addresses variations in data that are not caused by the object or scene scanned, such as scanner malfunction, topographic effects, lack of radiometric calibration between sensors, and atmospheric interference (ERDAS 2003). Both the atmospheric and radiometric corrections were combined using the image-based COST model (Figure 5.3) of Chavez (1996). The model was designed for TM5 multispectral data with six bands, however, the model was modified to fit for MSS and ASTER images with four bands.

The inputs to the COST model of Chavez (1996) are the Earth-Sun Distance, sun elevation angle, and minimum decimal number (DN) values for each band. The model first converts each minimum DN value to an at-satellite minimum spectral radiance value:

\[ L_\lambda = L_{\text{MIN}_\lambda} + Q_{\text{CAL}} \ast (L_{\text{MAX}_\lambda} - L_{\text{MIN}_\lambda}) / Q_{\text{CALMAX}} \]  

(Eqn. 5.1)
where QCAL is minimum Digital numbers (DN), QCALMAX = 255, and constants LMIN, LMAX are given in Table 2 of Markham and Barker (1986).

For each band, the theoretical radiance of a dark object (assumed to have a reflectance of 1% by Chavez 1996) is computed:

\[
L_{\lambda, 1\%} = 0.01 \times d^2 \times \cos^2 \theta / (\pi \times ESUN_{\lambda}) \quad (Eqn. 5.2)
\]

where ESUN_{\lambda} = mean solar exoatmospheric spectral irradiance from Table 4 of Markham and Barker (1986), d is the sun-earth distance, and theta is the solar zenith angle (90-sun elev).

A haze correction was computed using the computed dark object values (Chavez 1996):

\[
L_{\lambda, haze} = L_{\lambda} - L_{\lambda, 1\%} \quad (Eqn. 5.3)
\]

The fundamental radiance to reflectance (rho) equation is:

\[
P = \pi \times d^2 \times (L_{\lambda} - L_{\lambda, haze}) / ESUN_{\lambda} \times \cos^2 \theta \quad (Eqn. 5.4)
\]

The output from the model is in reflectance units, ranging from 0 to 1, except very bright objects such as snow or clouds which might have values > 1.0.

Mosaicking and Subsetting. More than one satellite image was needed to cover the study area and mosaicking two or more images was necessary. However, the resulting
mosaic image was much larger than the study area. Thus, it was beneficial to reduce the size of the image and include only the area of interest. Image subsetting helps to cut out the unnecessary data from the file and increase the data-processing speed. The vector file defining the boundary of the study area was used to mask the image and cut the area of interest from all satellite imagery.

Ground Truthing and Image Classification. Ground-truth data are necessary for classification of satellite imagery and accuracy assessment (Congalton 1991). Prior to preprocessing and classification of the satellite imagery, ground-truth data were collected using Garmin II Plus Global Positioning System (GPS) equipment. In 2005-2006, an extensive field survey was carried out at Allideghi Plain and important sites within the district. During this survey, point data were collected to obtain accurate locations of each land-cover type for the creation of training sites and accuracy assessment.

Efforts were made to collect training points in homogenous cover classes greater than 90 x 90 m, much larger than the spatial resolution of the finer ASTER imagery (15 x 15 m) and roughly coincident with a 3 x 3 pixel grouping of TM data. Acquisition dates of the ASTER imagery and ground-truth data were different and thus the point data were collected for areas that were unchanged through 2005-6 for all cover classes. The point data were then re-projected to UTM Zone 37, WGS 1984 and exported as ArcMap shape files.

For some cover classes, fewer points and smaller areas were used based on their specific size, abundance, and accessibility. Even though there were some GPS points taken at the edge of water bodies and at the edge of P. juliflora thickets, and Acacia shrublands, these points were not used for ground truthing and accuracy assessment.
Rather, training points were selected from the imagery. In addition, the plantation (the image was taken after cotton was harvested) was classified separately since the training signatures taken from these areas were similar with those of the grassland.

The ASTER imagery of 2005 with a spatial resolution of 15 m x 15 m was used to classify the vegetation following supervised classification with Maximum Likelihood Classification Algorithm using ERDAS IMAGINE software. Six land-cover types were identified: grassland/wooded grassland, *Acacia* shrubland, *P. juliflora* shrubland, water bodies, plantation, degraded shrubland and volcanics.

*Image processing for Change Detection*

Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times. Several change-detection algorithms have been developed over the last two decades because of increasing versatility in manipulating digital data and increasing computing power (Singh 1989, Sohl 1999, Jensen 2005). The two common methods of change detection for remotely sensed images are band subtraction and band ratioing.

Visual Composite Image Change Detection. Multi-date visual change-detection technique using write-function memory insertion provides a simple mechanism to display changes between two dates of imagery quickly and efficiently, but it does not provide quantitative information on the amount of area changing from one land-cover type to another (Singh 1989, Jensen 2005). This technique involves the use of one band from each date of imagery. Each band is put in an image plane to create a layer stack and the composite is displayed. For this study, the Red and Near Infrared bands were selected to show the vegetation change that occurred since 1973. For example, the NIR band of the
2005 ASTER image was displayed through the R (red) and G (green) channel and that of the 1973 MSS image was displayed through the B (blue) channel. The same holds true to identify the land-cover change between 1973-86, and between 1986-2005. The resulting image will be shades of yellow in areas with higher brightness values in the recent 2005 image (vegetation increase) and as shades of blue in areas with higher brightness values in the older image (vegetation decrease). This technique helps to visualize and identify areas that have changed during the specific period of time.

Image Differencing Techniques. Image differencing might be the most widely applied change-detection algorithm (Singh 1989, Coppin et al. 2004). According to Singh (1989), Macleod and Congalton (1998), and Coppin and Bauer (1994) image differencing appears to perform generally better than other methods of change detection. Macleod and Congalton (1998) also found out that the image-differencing change-detection technique had the highest accuracy for identifying changes in eelgrass meadows than the post-classification and principal components analysis. Image differencing involves subtracting the first date of original or transformed (e.g. NDVI) imagery from a second date that have been precisely registered to the same coordinate system. In image differencing, two co-registered images of two dates are subtracted pixel by pixel of selected bands or vegetation indices to produce a new change image between two dates (Singh 1989, Jensen 2005). However, this method will not help to determine the 'from-to' change of land-cover types.

Change Detection by Band Differencing. Band differencing is performed by subtracting the brightness or reflectance value of one date of a given band from the brightness value of the same band of another date (Eqn 5.5). Subtraction of spatially
registered images of time 1 and time 2, pixel by pixel produces an image showing the change between the two dates (Singh 1989, Jensen 2005). The change image has positive and negative values in areas where reflectance change occurs and zero or near zero in areas where no change between two dates (Grey et al. 1998, Jensen 2005).

\[ \Delta BV_{ijk} = BV_{ijk} (1) - BV_{ijk} (2) + C \]  \hspace{1cm} (Eqn.5.5)

where \( \Delta BV_{ijk} \) = Change pixel value, \( BV_{ijk} (1) \) = Brightness value on date 1, \( BV_{ijk} (2) \) = Brightness value on date 2, \( C \) = Constant (e.g. 1) offset to produce positive DNs, \( i \) = Line number, \( j \) = Column number, \( k \) = Single band

In order to emphasize vegetation change, the Red and Near Infrared bands were used from each of the respective images (Grey et al. 1998) because visible red and NIR bands are useful for discriminating vegetated and non-vegetated areas (Singh 1989, Sohl 1999, Jensen 2005). Vegetation reflection is maximum at the shorter near-infrared range and chlorophyll absorption is maximum at the visible red band and thus these shorter wavelength bands are important for investigations of vegetation (Macleod and Congalton 1998, Jensen 2005). For each band, the brightness value of every pixel from the 1986 TM image was subtracted from the brightness value of the same pixel of the 1973 MSS. Similarly, the 2005 ASTER bands were subtracted from the respective TM bands, respectively. Results of the image-differencing technique illustrate the pixels that have changed between the two time periods.

An important part of image processing is deciding where to place the threshold boundaries between change and no-change pixels (Singh 1989, Sohl 1999). Different
threshold values based on standard deviations from the mean (half, one, and two) were used on the new image to determine the change and unchanged pixels between the two time periods. Since the main objective of this study is to determine the conversion of grazing lands to *P. juliflora* shrubland, the vegetation classification performed on the ASTER image was used to identify the areas which changed due to the invasion of *P. juliflora*. This is because it is difficult to classify the older images due to lack of ground-truth data for training development.

Change Detection by Vegetation Index Differencing. In vegetation studies, Normalized Difference Vegetation Index (NDVI) is used to enhance the spectral differences between the strong reflectance of vegetation in the near-infrared part of spectrum and the chlorophyll absorption band (red part) of the spectrum (Singh 1989). The NDVI is the ratio of red and NIR bands computed from the equation below for all the images (Eqn 5.6). In the resulting image, vegetated areas will generally yield high values for the NDVI index because of their relatively high reflectance in NIR and low reflectance in the visible wavelengths. On the contrary, water and bare soil will have higher reflectance in visible wavelengths than in the NIR, thus these features yield negative and near-zero values.

\[
NDVI = \frac{\text{Near IR} - \text{Red}}{\text{Near IR} + \text{Red}} \quad (\text{Eqn.5.6})
\]

The resulting NDVI images were also used with the subtraction method to detect change over the range of time between two specific data acquisition dates. In the image-differencing procedure for change detection, the corresponding pixel values of the NDVI
image from date one \( (t_1) \) were subtracted from those of date two \( (t_2) \) as shown in the equation 5.7 below.

\[
\Delta \text{NDVI} = \text{NDVI}_{ij} (t_1) - \text{NDVI}_{ij} (t_2) \quad \text{Eqn.5.7}
\]

where, \( \Delta \text{NDVI} \) – Change in NDVI value

\( \text{NDVI}_{ij} (t_1) \) – NDVI value of date 1

\( \text{NDVI}_{ij} (t_2) \) – NDVI value of date 2

\( ij \) - Pixel coordinate

The lighter areas on the change image represent those where maximum change has occurred through time. The difference in areas of no-change has very small values approaching zero. On the other hand, areas of change manifest larger negative or positive values. Image statistics were then used to define the level of change intensity. Pixel values greater than half a standard deviation from both sides of the mean served as an interval to classify changed and unchanged areas (Grey et al. 1998). The standard deviation levels were then assigned different colors. By applying the individual colors and brightness levels, quantifiable changes may be visualized for each tail of the image histogram (Grey et al. 1998).

**Results**

*Write-Function Memory Insertion (WFMI)*

As shown in Figure 5.4 (a-f), it is evident that significant change had occurred in the vegetation cover of Amibara District between 1973 and 2005. As mentioned earlier,
all three images were taken during the dry period of the year, and the natural vegetation in most cases—except riverine vegetation—is dry. Thus, there was a clear increase in green vegetation (shown in yellow) in the West during the period 1973 to 1986 [Figure 5.4 (a,d)]. This increase is mostly on the agricultural areas and some in the rangeland. In 1973, prominent green vegetation was limited to strips of riparian sites along the Awash River to the West. The area used for plantations was relatively small in 1973. However, the plantation area increased markedly by 1986 with further expansion by 2005. This expansion is not directly apparent from the increase in green vegetation because of differences in harvest time among the three years.

During the period 1986 to 2005 the amount of green cover increased in the riparian zone to the West as well as rangeland areas to the West and East [Figure 5.4 (b,e)]. The rangeland area to the East included part of the Allideghi Plain which underwent dramatic change. The green vegetation in the agricultural areas decreased (shown in blue) during the same period. The difference in harvest time among the years makes it difficult to determine the pattern of change (increasing or decreasing vegetation cover) between the two periods (1973-86 and 1986-2005). In general, this method was effective to highlight changes in a qualitative fashion.

Band and NDVI Differencing

Results using band differencing and NDVI differencing are shown in Figure 5.5 to 5.7. In general, there were no clear patterns of increase or decrease of vegetation cover between the period of 1973-1986 and 1986-2005 using these approaches. This was because of agricultural harvest patterns and agricultural expansion as mentioned above.
However, there was a clear pattern of increase in green vegetation especially from 1986 to 2005 in rangelands and along the Awash River. It is important to recall that all the images were taken during the dry season when most of the natural vegetation in rangelands has undergone senescence. Much of the change (increase in green vegetation) that occurred between 1973 and 1986 was in the agricultural areas [Figure 5.6(d,e) and 5.7(d,e)]. However, there was also some increase in green vegetation on the western side of the rangelands beyond the plantation. The change (increase in green vegetation) that occurred between 1986 and 2005 was in the rangelands, and thus this second period was the focus of further analysis.

In general, results from all three differencing techniques were in agreement that green vegetation increased in the rangelands from 1986 to 2005 [Figure 5.5(a-c), 5.6(a-c), and 5.7(a-c)]. This was evident even at the two standard-deviation threshold especially for the western portion of the district [Figure 5.5(c), 5.6(c), and 5.7(c)]. The agricultural areas lost green vegetation during the same period because images from 2005 were taken after peak biomass harvest.

Table 5.4 illustrates the land-cover change for the district on a quantitative basis, using the three thresholds based on standard deviations from the mean. The red-band, NIR-band, and NDVI differencing approaches detected losses of vegetation cover on 6.0, 23.3, and 10.5% of the district, respectively, at the one standard-deviation threshold during the period 1986 to 2005. All three approaches detected increases in green vegetation during the same period in the district. The red, NIR, and NDVI approaches detected increases of 27.3%, 4.2%, and 3.9% of the district, respectively, at the one standard-deviation threshold. The increase in green vegetation cover occurred in the
rangelands; however, losses occurred both in the rangelands and agricultural areas [Figure 5.5(a-c), 5.6(a-c) and 5.7(a-c)].

Red-band differencing detected more green vegetation gain than loss and NIR and NDVI differencing detected more loss compared to the gain in the same period. The NIR differencing also detected more loss than did the red band and NDVI differencing. Despite these variations, at least 15,000 ha of the district gained green vegetation in the rangelands between 1986 and 2005 according to results from all methods at the one standard-deviation threshold. This indicates that the rangeland, which used to be dry in January when the images were taken, has changed to other vegetation types during the past 19 years. For all approaches, the district area that was unchanged from 1986 to 2005 was over 65% [Figure 5.6(b,e,h) and 5.7(b,e,h)].

Unlike the other techniques, red-band differencing detected the green vegetation gain at Allideghi Plain at the half standard-deviation threshold even though red-band differencing appears to have overestimated vegetation change for the district (Figure 5.5a). In general, the areas that have undergone dramatic green vegetation gain were mostly to the West of the district. This was also indicated even by the higher standard-deviation thresholds. Overall, the NDVI-differencing technique depicted the major land-cover change pattern well at the half standard-deviation threshold except for the change at Allideghi Plain (Table 5.4).

*Land Cover Classification*

The percentages of pixels used for ground truthing of cover types are shown in Table 5.5. Because of variation in accessibility of some areas it was difficult to obtain a
high percentage of training locations in each cover type. An attempt was made to get homogenous samples from each cover class, especially for the grassland and *P. juliflora* shrubland to serve as a base map for future monitoring and planning.

The ASTER image was classified into seven cover types: grassland, *Acacia* shrubland, *P. juliflora* shrubland, water, volcanics, plantation and open shrubland/woodland (Figure 5.8). The similarity in signature values of training sites for grassland/wooded grassland and shrubland cover types, in particular, made it difficult to separate these two categories in some cases. In addition, the green natural vegetation to the East of the district had similar signature values with that of the *P. juliflora* cover type.

Accurate estimation of the contribution of various cover types to the district was difficult because of reasons given above. The distinctive cotton-plantation cover type, however, currently covers about 18,000 ha with some clusters of *P. juliflora* on the edges. This is about 5% of the district (392,000 ha). Water and volcanic areas cover about 3,000 and 7,000 ha, respectively. The *P. juliflora* shrubland has recently expanded to cover an area of about 40,000 ha which is about 10% of the total district area. The remaining 75% of the district is covered with grassland, wooded grassland and shrubland.

**Discussion**

The WFMI technique was helpful to identify changes that occurred between two dates of imagery acquisition in a qualitative fashion. Despite the land-cover change that occurred because of agricultural area expansion and differences in harvest time among the years, a visual interpretation of the images indicated that significant land-cover change occurred in the rangelands of the district during the past 32 years. Green
vegetation has increased on the rangelands, replacing the natural savanna which used to be dry during January, especially during the past 19 years. The visual interpretation of multi-temporal images is thus an important and valuable method for rapid analysis of qualitative change detection (Lu et al. 2004, Vijayaraj et al. 2005). It can also be used on a preliminary basis to determine suitable methods for quantitative change detection and to subjectively compare automated change detection results (Vijayaraj et al. 2005).

Image algebra approach (band differencing and vegetation index differencing) is important to detect all changes greater than the identified thresholds (Lu et al. 2004), as land-cover change in general is identified as those values beyond a specified threshold (Jensen 2005, Singh 1989). The main disadvantage of image algebra is the difficulty of selecting suitable threshold values based on standard deviations to identify changed and unchanged areas (Lu et al. 2004, Jensen 2005).

In this study, there was no consistency among the three image-algebra techniques used to quantify land-cover change using all three thresholds. The red-band differencing estimates were two- to six-times higher for areas which gained green vegetation when compared to results from the other two techniques in the same period. In contrast, red-band differencing detected less area which lost green vegetation cover compared to that estimated by the other two techniques. However, all have shown that there was both an increase in green vegetation and decline of vegetation cover during the past 32 years, regardless of the differences in the amount of changed area. Singh (1989) and Fung (1990) indicated that evaluation of results using different change-detection techniques produced different maps of change in the same environment.
There are reports that indicated red-band differencing provides more accurate identification of vegetation change than does NDVI differencing in arid and semi-arid environments (Pilon et al. 1988, Chavez and Mackinnon 1994). Others report no significant difference in image-band differencing and NDVI differencing to detect land-use changes (Prakash and Gupta 1998). In this study, red-band differencing results might have over-estimated the green vegetation increase in the district at the half standard-deviation threshold. However, it helped to pick up the change at the Allideghi Plain, which is relatively drier than the western part of the district around the Awash River. The NIR band-differencing, on the other hand, could not detect the green vegetation increase which was detected by the other two techniques even at the two standard-deviation threshold. The NDVI differencing at a half standard-deviation seems very important to show the prominent pattern of increased green vegetation in the rangelands, except for those sites on relatively drier areas.

In general, during the past 32 years, there was both land-use and land-cover change in the district. The major land-use change that occurred between 1973 and 1986 was associated with the expansion of agricultural areas and temporal shifts in harvest periods. This was clearly seen on the images because of the sharp nature of the boundaries of plantations. Getachew (2001) also reported that area under cotton plantation has increased from 3,500 ha in 1973 to about 12,300 ha in 1995. The increase in green vegetation between 1986 and 2005 occurred in terms of natural vegetation, primarily in the western part of the district along the Awash River. Some vegetation cover loss occurred both on the rangelands and on agricultural areas.
The major challenge of change detection in land-cover is identifying the causes of changes (Singh 1989). The change that occurred between 1986 and 2005 was partly due to shifting the composition of the natural vegetation and partly due to loss of vegetation cover. The shift in composition occurred mainly on the traditional dry-season pastoral grazing lands. This was mainly due to encroachment of woody species, *P. juliflora*. This result coincides with the introduction of *P. juliflora* in the 1970s, planting programs in 1986 and 1988, and reports of its subsequent expansion in dry-season pastoral grazing areas as well as the Allideghi Plain (Chapter 4). *Prosopis juliflora* has created an increase in green vegetation cover, especially in the western part of the district.

Part of vegetation cover loss might be due to heavy livestock grazing and trampling on the herbaceous vegetation of the rangelands. This might be a sign of declining forage productivity of residual grazing areas unaffected by *P. juliflora*. The difference in harvest time in the agricultural areas has also contributed to part of the vegetation loss in the same period. In addition, charcoal production, which is especially prominent along the Addis Ababa-Djibouti highway, might also contributed for the loss of vegetation cover.

**Conclusions**

All change-detection techniques used in this study were relatively rapid and easy to use. It was not possible to provide information about “from-to” change in all the techniques. In image-algebra techniques, however, it was especially difficult to determine the appropriate threshold boundary between sites that showed “change” versus those that showed "no change." In general, all techniques showed that the semi-arid savannah
ecosystem of the district of Amibara experienced both land-use and land-cover change during the past three decades. About 30,000 ha of formerly dry-season grazing land have been covered by *P. juliflora*. Areas which have lost herbaceous vegetation might be at risk of invasion by *P. juliflora*. Since land cover and/or land-use change data are very important in conservation planning, this study gave preliminary results of vegetation change in Amibara District. Further studies are necessary to determine the expansion rate of *P. juliflora* and the effectiveness of management strategies underway (see Chapter 4).

**References**


ERDAS IMAGINE Tour Guides. 2003. ERDAS IMAGINE V 9.0, ERDAS, Inc. Atlanta, Georgia, USA.


<http://www.eoearth.org/article/Woody_encroachment_in_the_southwestern_United_States>


Lass, L.W., Prather, T.S., Glenn, N.F. et al. 2005. A review of remote sensing of invasive weeds and example of the early detection of spotted knapweed (Centaurea maculosa) and babysbreath (Gypsophila paniculata) with a hyperspectral sensor. - Weed Sci. 53: 242-251.


Table 5.1. Satellite imagery acquired from Global Land Cover Facility (GLCF) (http://glcfapp.umiacs.umd.edu) for MSS and TM imagery and Land Processes Distributed Active Archive (LP DAAC) which is part of NASA’s Earth Observing System (EOS) Data Gateway (http://lpdaac.usgs.gov/main.asp) for ASTER imagery.

<table>
<thead>
<tr>
<th>ID</th>
<th>WRS (^1): P(^2)/R(^3)</th>
<th>Acquisition Date</th>
<th>Dataset</th>
<th>Producer</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>029-706</td>
<td>1: 180/053</td>
<td>1973-01-30</td>
<td>MSS</td>
<td>EarthSat</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>034-862</td>
<td>1: 180/054</td>
<td>1973-01-30</td>
<td>MSS</td>
<td>EarthSat</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>012-358</td>
<td>2: 167/053</td>
<td>1986-01-30</td>
<td>TM</td>
<td>EarthSat</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>012-359</td>
<td>2: 167/054</td>
<td>1986-01-30</td>
<td>TM</td>
<td>EarthSat</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>AST_L1B_003</td>
<td>WRS 2</td>
<td>2005-01-01</td>
<td>ASTER</td>
<td></td>
<td>GDS(^4) GeoTIFF</td>
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<tr>
<td>AST_L1B_003</td>
<td>WRS 2</td>
<td>2005-01-01</td>
<td>ASTER</td>
<td></td>
<td>GDS GeoTIFF</td>
</tr>
<tr>
<td>AST_L1B_003</td>
<td>WRS 2</td>
<td>2005-01-01</td>
<td>ASTER</td>
<td></td>
<td>GDS GeoTIFF</td>
</tr>
</tbody>
</table>

\(^1\)– World Reference System; \(^2\)– Path; \(^3\)– Row; \(^4\)– Ground Data System.

Table 5.2. Orbit and acquisition characteristics of the imagery\(^1\)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Swath (km)</th>
<th>Scene size (km)</th>
<th>Altitude (km)</th>
<th>Revisit (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L 1-5</td>
<td>MSS</td>
<td>180</td>
<td>180 x 170</td>
<td>917</td>
<td>18</td>
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<td>L 4-5</td>
<td>TM</td>
<td>185</td>
<td>170 x 183</td>
<td>705</td>
<td>18</td>
</tr>
<tr>
<td>L 7</td>
<td>ETM+</td>
<td>185</td>
<td>170 x 183</td>
<td>705</td>
<td>16</td>
</tr>
<tr>
<td>Terra</td>
<td>ASTER</td>
<td>60</td>
<td>60 x 60</td>
<td>705</td>
<td>16</td>
</tr>
</tbody>
</table>

\(^1\) http://glcfapp.umiacs.umd.edu
Table 5.3. Radiometric characteristics of the satellite imagery\(^1\).

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Spectral Resolution ((\mu)m)</th>
<th>Band</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landsat 1-3</strong></td>
<td>MSS</td>
<td>Band 4: 0.50-0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 5: 0.60-0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 6: 0.70-0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 7: 0.80-1.10</td>
</tr>
<tr>
<td><strong>Landsat 4-5</strong></td>
<td>TM</td>
<td>Band 1: 0.45-0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 2: 0.52-0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 3: 0.63-0.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 4: 0.760-0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 5: 1.55-1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 7: 2.08-2.34</td>
</tr>
<tr>
<td><strong>Terra</strong></td>
<td>ASTER VNIR(^2)</td>
<td>Band 1: 0.52-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 2: 0.63-0.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 3N: 0.78-0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Band 3B: 0.78-0.86</td>
</tr>
</tbody>
</table>

\(^1\) http://glcfapp.umiacs.umd.edu

\(^2\) band 1-3 - Nadir looking; Band 4 - Backing looking
Table 5.4. Land cover change statistics for the district of Amibara using three change detection techniques and three standard deviation thresholds from 1973 to 2005.

<table>
<thead>
<tr>
<th>Change Detection Techniques</th>
<th>Year</th>
<th>Area</th>
<th>± 0.5 SD</th>
<th>± 1 SD</th>
<th>± 2 SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>tve$^3$</td>
<td>0$^4$</td>
<td>-ve$^5$ tve</td>
</tr>
<tr>
<td>Red Band</td>
<td>1986 - 1973 Ha</td>
<td>138,648</td>
<td>175,381</td>
<td>77,549</td>
<td>98,161</td>
</tr>
<tr>
<td>differencing</td>
<td>%</td>
<td>35.4</td>
<td>44.8</td>
<td>19.8</td>
<td>25.1</td>
</tr>
<tr>
<td>%</td>
<td>39.4</td>
<td>40.4</td>
<td>20.2</td>
<td>27.3</td>
<td>66.7</td>
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<tr>
<td>%</td>
<td>37.1</td>
<td>43.1</td>
<td>19.8</td>
<td>26.4</td>
<td>68.0</td>
</tr>
<tr>
<td>NIR Band</td>
<td>1986 - 1973 Ha</td>
<td>69,868</td>
<td>163,575</td>
<td>158,136</td>
<td>22,977</td>
</tr>
<tr>
<td>differencing</td>
<td>%</td>
<td>17.8</td>
<td>41.8</td>
<td>40.4</td>
<td>5.9</td>
</tr>
<tr>
<td>2005 - 1986 Ha</td>
<td>67,381</td>
<td>192,615</td>
<td>131,583</td>
<td>16,290</td>
<td>283,989</td>
</tr>
<tr>
<td>%</td>
<td>17.2</td>
<td>49.2</td>
<td>33.6</td>
<td>4.2</td>
<td>72.5</td>
</tr>
<tr>
<td>2005 - 1973 Ha</td>
<td>62,361</td>
<td>189,257</td>
<td>139,961</td>
<td>17,526</td>
<td>281,088</td>
</tr>
<tr>
<td>%</td>
<td>16.0</td>
<td>48.3</td>
<td>35.7</td>
<td>4.5</td>
<td>71.8</td>
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<tr>
<td>Change Detection Techniques</td>
<td>Year</td>
<td>Area</td>
<td>± 0.5 SD</td>
<td>± 1 SD</td>
<td>± 2 SD</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------</td>
<td>------</td>
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<td>--------</td>
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<td>0³</td>
<td>-ve³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>9.8</td>
<td>49.3</td>
<td>40.9</td>
</tr>
<tr>
<td></td>
<td>2005 - 1986</td>
<td>Ha</td>
<td>27,697</td>
<td>255,521</td>
<td>108,362</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>7.1</td>
<td>65.2</td>
<td>27.7</td>
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<tr>
<td></td>
<td>2005 - 1973</td>
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<td>31,945</td>
<td>199,457</td>
<td>160,178</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>8.2</td>
<td>50.9</td>
<td>40.9</td>
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1 Red and NIR bands and NDVI differencing.
2 ± 0.5, 1, and 2 standard deviation from the mean.
3 Vegetation cover gain.
4 No land-cover change.
5 Vegetation cover loss.
Table 5.5. Percent of images sampled for ground truthing by land cover types.

<table>
<thead>
<tr>
<th>Cover types</th>
<th>No. of Ground Truth Pixels</th>
<th>% of Ground Truth Pixels of the Total</th>
</tr>
</thead>
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<tr>
<td>Grassland</td>
<td>11,150</td>
<td>0.23</td>
</tr>
<tr>
<td><em>P. juliflora</em> shrub land</td>
<td>17,905</td>
<td>0.37</td>
</tr>
<tr>
<td><em>Acacia</em> shrub land</td>
<td>8,338</td>
<td>0.17</td>
</tr>
<tr>
<td>Plantation</td>
<td>4,000</td>
<td>0.08</td>
</tr>
<tr>
<td>Water</td>
<td>2,680</td>
<td>0.06</td>
</tr>
<tr>
<td>Volcanics</td>
<td>3,508</td>
<td>0.07</td>
</tr>
<tr>
<td>Open shrubland/woodland</td>
<td>1,987</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>49,568</td>
<td>1.03</td>
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</table>
Figure 5.1. Map showing Amibara District located in Zone 3, Afar Regional State, Ethiopia.
Figure 5.2. Satellite Image processing flow chart for change detection and land cover classification.
**Figure 5.3.** COST model for atmospheric and radiometric correction of six band images (Source: Chavez 1996).
Figure 5.4(a-f). Change detection using Write-Function Memory Insertion for ASTER 2005, TM 1986 and MSS 1973 images. In the NIR band combination images, areas with higher brightness value in the recent image appear as shades of yellow, and areas with higher brightness values in the older image as blue. In the red band combination images, areas with higher brightness values in the recent image appear as shades of blue, and areas with higher brightness values in the older image as yellow.
Figure 5.5(a-i). Change detection using the visible red band-differencing algorithm. (Note: areas classified as vegetation gain are generally characterized by lower reflectance values in the red band as compared to areas classified as vegetation loss that are generally representative of higher reflectance values.)
Figure 5.6(a-i). Change detection using Near Infrared band-differencing algorithm. (Note: areas classified as vegetation gain are generally characterized by higher reflectance values in the NIR band as compared to areas classified as vegetation loss that are generally representative of lower reflectance values.)
Figure 5.7(a-i). Change detection using NDVI band differencing.
Figure 5.8. Land-cover types of Amibara Wereda (2005).
Summary of Research Results

Introduction

In the past, the Allideghi Wildlife Reserve (AWR) was used as a temporary, seasonal forage source for Afar pastoralists while serving as a sanctuary for wild animals, including the endangered Grevy’s Zebra. The general reduction in alternative forage resources for pastoralists in the district of Amibara has consequently led to the establishment of artificial water sources and permanent pastoral settlements in AWR. The associated dispersal of _P. juliflora_ in and around the district imposes more pressure on the grazing systems for livestock and wildlife. The main objective of this study was to determine the effects of pastoralist activities and encroachment of _P. juliflora_ on the future sustainability of the AWR grassland to support a viable population of Grevy’s Zebra and other wild grazing animals, while also providing forage for pastoral livestock.

Wildlife and Livestock Resource Use Patterns

Resource use patterns of livestock at AWR, specifically at the Allideghi Plain, have changed from the previous temporary use to permanent use due to a shortage of forage in other parts of the district. Forage sources declined initially due to agricultural expansion and this was exacerbated further by the encroachment of _P. juliflora_ on dry-season grazing lands. Currently, the resource use pattern of livestock at Allideghi is determined by availability of water. The utilization area expands during the wet season and contracts during the dry season. The Allideghi Plain rests from livestock grazing for
only about a month per year at a time when soil moisture is low for plant growth. The
current resource-use pattern may not give intensively grazed areas enough time to
recover. In addition, some grassland sites that have been intensively used by livestock
have been invaded by \textit{P. juliflora}, and they no longer have high-value herbaceous forages
in the understory.

Grazing patterns of larger wild herbivores in contrast, were more limited by
human interference. Most wild herbivores were often observed grazing in relatively close
proximity to livestock, but typically such livestock were unaccompanied by herders and
were further from settlements. Overlap of resource use between livestock and wild
ungulates might indicate potential competition for forage. Grevy’s Zebra were unusual in
that they showed the lowest degree of association with livestock in all seasons. An
absence of water on the plains during the dry season forces wild animals to travel further
to get water from hot springs and rivers. As livestock and humans use these limited
permanent water sources during the day, wild animals access them at night, exposing
themselves and their young to predation from hyenas or lions in the process. Such limited
access to water might be a determining factor for the survival of wild ungulates.

\textit{Impact of Livestock Grazing}

Water-centered livestock grazing has created a large piosphere, a zone largely
devoid of vegetation and exposed to erosion. Standing-crop biomass declined along the
grazing gradient with increased proximity to the watering site. Plant composition
underwent dramatic change from grass domination to forb domination nearer the
watering site. Perennial grasses cannot tolerate the repeated impacts of livestock grazing
and trampling and they are eventually replaced by less palatable forb species. As
expected, utilization was highest at intermediate levels of impact in accordance with the availability of palatable forage. Above-ground net primary production (ANPP) and species richness of herbaceous vegetation at severely grazed sites were significantly lower than those at the control sites. Sites further from the water point, however, showed resilience in terms of grassland productivity and species richness of the herbaceous vegetation.

Impacts of P. juliflora

*Prosopis juliflora* was introduced to the Ethiopian Rift Valley in the 1970s and later planted in 1986 and 1988 in degraded areas. It then spread to dry-season grazing lands and the Allideghi Plain via livestock. At the beginning it was a widely accepted plant because of its utility for shade, fuel, and supplemental forage. The attitudes of Afar pastoralists towards this species have changed, however, as a result of observing the negative impacts on grazing lands, livestock, and people. Town people, however, still appreciate the plant for fuel and as a source of income. Encroachment of *P. juliflora* is one of the major factors that has contributed to a reduction of forage which might limit livestock production. This has initiated a management strategy focusing on exploitation of the plant and its products and conversion of cleared sites for other uses. The majority of such efforts, however, were not focusing on the main goal of controlling the spread of this plant, but rather on income generated from activities such as charcoal production. The pastoralists are still seeking other means such as the use of chemicals to eradicate *P. juliflora* from their grazing lands.

At the Allideghi Plain, *P. juliflora* establishment follows settlements, corrals, livestock trails, and other areas which are used by livestock. The different growth stages
of *P. juliflora* have significantly reduced species richness and basal cover, and
changed species composition, of herbaceous vegetation. Herbaceous vegetation cover
was reduced by 90% under the stands of large *P. juliflora*. The magnitude of impact
appeared to be greatest on grasses rather than forbs.

**Vegetation Change**

The study on land-cover change covered the whole district of Amibara. All the
change-detection techniques used indicated there was a significant change (both increase
and decrease) in vegetation cover of the district during the period 1973 to 2005. The
increase in green vegetation between 1973 and 1986 was primarily on the agricultural
areas due to a shift in the timing of crop cultivation. During the period 1986 to 2005, the
amount of green vegetation cover increased in riparian zones and on rangeland areas,
especially in the west. This was evident even at a two standard-deviation threshold. All
the techniques indicated that at least 15,000 ha of the district gained green vegetation
between 1986 and 2005 at the one standard-deviation threshold, despite variation among
techniques in depicting change area. The increase in green vegetation during 1986 to
2005 coincides with the introduction, planting programs, and reports of expansion of *P.
juliflora* on dry-season pastoral grazing areas. The loss in green vegetation during this
period occurred as a result of a temporal shift in harvest and possibly because of heavy
grazing on rangelands.

**Conclusions**

In nomadic pastoralism and transhumance systems, livestock production was
traditionally based on efficient use of seasonally available resources and posed only a
moderate risk for degrading the environment (Coughenour 1991, Fleischner 1994, Nautiyal et al. 2003). According to Bourn and Blench (1999), areas with low rainfall and limited potential for arable farming, where human population density is relatively low, and where livestock owners predominate, have the best prospects for demonstrating sustainable co-existence of livestock and wildlife in East Africa. Homewood and Rodgers (1984) reported that there was no pastoralist-induced environmental degradation within the traditional subsistence pastoral system in the Ngorongoro Conservation Area (NCA). However, the current situation in NCA has apparently changed and is not sustainable; human welfare cannot be enhanced there now without compromising wildlife conservation (Galvin et al. 2006).

In Ethiopia, the contribution of mobile pastoralism for the protection of the environment has not been well recognized and appreciated. There have been many official efforts to resettle and sedentarize people against their will. In addition, development interventions such as large-scale agricultural schemes, urbanization and other natural and human-induced factors have increased pressure on the nomadic way of pastoral life and have resulted in widespread sedentarization (Gebre 2004, Tesfay and Tafere 2004). This overall pattern has indeed been exemplified at AWR.

Shortage of forage resources due to agricultural expansion, and later due to invasion of *P. juliflora* on dry-season grazing lands, has forced the Afar pastoralists to change their traditional temporary use patterns of the AWR. This was realized with the introduction of artificial water sources and establishment of permanent settlements. Thus, any possible harmonious relationship between pastoralism and wildlife at AWR was disrupted when the traditional, pastoral system of transient use was replaced by
permanent use. This has prevented the opportunity for intensively grazed sites to rest following grazing. Periodic resting of grazed sites is an important component of sustainable pastoralism in rangelands (Freudenberger and Hacker 1997). The livelihood of the people (i.e., keeping many livestock) also hasn’t changed in response to new ecological conditions. Such imbalances between the modern and traditional pastoral practices can create enhanced risk for environmental degradation (Lusigi et al. 1984).

This study has clearly shown the long-term negative impacts of water-centered grazing on the herbaceous vegetation. However, the grassland exhibits resilience to grazing pressure in terms of productivity and species richness. This resilience may be conferred, in part, because of the landscape position of the Allideghi Plain. The plains collect moisture and nutrients during rainy periods, and this probably contributes to the ability of the perennial grasses to persist despite intensive grazing regimes. The fact that the ungrazed control site was formerly heavily utilized over a decade ago is a testament to the recovery potential of the herbaceous vegetation. Despite the resilience, it is a concern that the negative impacts will extend more widely as palatable forages are diminished near watering sites and more settlements and water sources are established.

Unlike the results of Reid et al (2003) in the Maasai Mara Reserve of Kenya where some wild ungulate species prefer to be in the proximity of people, probably as a means to reduce predation risk, all wild ungulates at AWR avoided people in general. Traditionally, both the Afar and Issa carry guns to protect themselves and their livestock from raids and predation. This is unlike the Maasai Mara situation where guns are not officially allowed. Some people have reportedly used guns to kill Grevy’s Zebra at AWR for its medicinal value as well as to kill carnivores which might attack livestock.
The current livestock grazing pressure and resource use patterns of livestock has created a vicious cycle of increased seed dispersal and establishment of *P. juliflora* at AWR. Land-use and land-cover changes due to agricultural expansion and invasion of *P. juliflora* resulted in concentrated grazing and a decline of forage availability in the district. This has increased the number of people and livestock using AWR and has reduced cover of herbaceous vegetation. As livestock are the major agents of *P. juliflora* seed dispersal, areas grazed by livestock become exposed to invasion (Archer et al. 1988, Brown and Archer 1989). This, coupled with the aggressive nature of *P. juliflora* will cause an irreversible displacement of the natural vegetation and a loss of biodiversity.

The increased population of livestock and humans dependent on AWR has probably increased competition between wild ungulates and livestock for forage. In addition, as more and more areas are affected by over-grazing and *P. juliflora* encroachment at AWR, wild ungulates will be pushed to unfavorable and less safe habitats. Others also reported that introduction of livestock changes the distribution of native wild ungulates (Austin and Urness 1986, Wallace and Krausman 1987, Young et al. 2005).

Despite the direct effects of livestock grazing, the grassland can recover if allowed to rest. However, it may be unable to recover from *P. juliflora* encroachment. Evidence suggests that without close supervision, "management through utilization" of *P. juliflora* will also be unsuccessful. The geographically isolated small population of Grevy’s Zebra at AWR is already more vulnerable to severe weather and disease (Moehlman 2005). Thus, the sustainability of AWR to be the remaining home of the endangered Grevy’s Zebra is under threat. The livelihood of Afar pastoralists is also
under threat with the current trends. Additional forage constraints will magnify the already existing tribal conflicts for remaining grazing areas (Berhanu and Tesfaye 2006).

**Management Implications**

The AWR is a protected area only on paper. Generally, there has not been budget allocation, personnel assignment, or infrastructure development to promote AWR since its establishment. It also has no legal status. Neither the regional nor the federal governments have any plan to manage the AWR at the time of this study. However, despite this lack of official attention, the national and international significance of AWR for the conservation of Grevy’s Zebra is unique. The current threats such as poaching and habitat loss associated with the possession of automatic weapons by Afar and Issa men, an increasing human and livestock population, the expansion of *P. juliflora*, the lack of legal status, and the absence of wildlife management interventions are all critical issues that underlie the future survival of Grevy’s Zebra and other wild animals at AWR.

Thus, the AWR needs immediate management attention from both the regional and federal governments to legalize its status and reduce or control the risks mentioned above. The northern and northeastern part of the plain which is situated between the Afar and the Issa and thus only infrequently grazed by livestock, might serve as a core area for wildlife conservation in the AWR. It is mainly a mix of grassland, woodland, and bushland which is suitable for the wildlife present in the AWR. However, any management activity should be integrated and include areas which are permanently and temporarily occupied by people and livestock but having different conservation priorities.
The populations of oryx, gazelle, and ostrich at AWR remain promising. Special attention is necessary for the Grevy’s Zebra because of the declining status of the species worldwide. If special protections are enacted, equid populations have been proven to have a high recovery potential in terms of increased birth rates, lowered age of sexual maturity, and increased genetic diversity (Rubenstein 2001). The endangered Grevy’s Zebras can thus serve as a “flagship species” for the conservation of biodiversity of the AWR in general.

In order to avoid conflicts with local communities, any approaches to manage the AWR must include local community involvement in planning and decision-making. The concept of maintaining wilderness for wildlife protection and thus excluding human influences is not valid for places like Ethiopia (Kay 1994). Community-based conservation, which involves local communities in resource planning, management, and economic profit sharing, is an important alternative to the exclusionary protectionist policies of the past (Hackel 1999). Such an approach will give local people a sense of ownership of natural resources. Participation of local communities planning and managing natural resources is widely considered as a means of sustaining protected areas (De Boer and Baquete 1998, Lewis 1993). This is because a sound management plan requires community participation, which in turn requires governments to gain community trust (Craven and Wardayo 1993). The future plan for AWR should create a compromise between wildlife conservation and the interests of the local people. However, joint use of the Allideghi Plain by two conflicting tribes (Afar and Issa) confirms the need for careful planning to involve the two tribes in community-based conservation. The local
governments should also give emphasis in resolving conflict between the Afar and the Issa to facilitate implementation of conservation efforts in the AWR.

Due to the population increases of people and livestock, and the declining status of natural resources, the cultural trend of the local pastoralists to protect wild animals is eroding. In addition, the people are experiencing livestock losses to predation. It might be difficult to get the support of local people for conservation of wildlife under such circumstances (Holmern et al. 2007). However, it is important to start community work at the AWR to strengthen the cultural ties of the people to wildlife and pass stronger ties on to the next generation. In addition, compensation payments might increase the tolerance of people towards wildlife conservation. Benefit sharing has been found to be a major factor influencing positive community attitudes towards wildlife conservation (Tessema et al. in press). Currently, the major source of cash income for the pastoralists at Allideghi is livestock sales. Some have ancillary income from cotton plantations. Additional income from tourism and associated activities could encourage local people to protect wild animals.

The existing livelihood system of pastoralists which is founded on livestock herding, is probably unsustainable as forage resources decline due to various reasons. The people at Allideghi know that the forage condition is deteriorating due to overgrazing and invasion of *P. juliflora*. Thus, there is a need to diversify their income through means which are compatible with wildlife conservation. One way for the government to do this is through establishing tourism facilities in the reserve which can create some job opportunities such as wildlife scouts and field guides, and from selling handicrafts and other cultural souvenirs. The tourism attraction of AWR could be successfully established
in association with the existing activities in the nearby Awash National Park and the volcanic attraction at Hertele.

The results from this study indicate substantial changes in plant composition that are related to the cumulative, long-term impacts of water-centered grazing. Thus, it is a high priority to limit further proliferation of artificial watering points and permanent settlements in the AWR. In the Maasai Mara reserve of Kenya, it was suggested that the number and location of settlements should be managed to protect the remaining wildlife populations (Reid et al. 2003).

The sustainability of AWR as a grassland-dominated ecosystem is primarily dependent on the control of *P. juliflora* dispersal. The scenario is that as the proliferation of *P. juliflora* in dry-season pastoral grazing areas increases, the number of livestock dependent on the Allideghi grassland will increase. This will further increase the number of settlements and permanent watering sites. This will increase the intensity of disturbances and the susceptibility of the native plant communities. Opportunities for establishment of invasive species will be created.

Control of *P. juliflora* is impossible in the current situation. Commercializing the harvest of this species (via charcoal production) without an ecological monitoring system invites abuse and associated problems. Further study of cleared sites is necessary to evaluate the effectiveness of various harvest techniques. Thus, management needs a stronger scientific basis to succeed. Government and NGOs also need to be directly involved in controlling *P. juliflora* without any financial benefits attached to the activities. In addition to the primary focus of controlling the spread of *P. juliflora* in well-established stands, equal focus is necessary to better control dispersal and establishment.
It is crucial that decision makers are involved in supporting ecological monitoring activities on the ground.

Findings reported here illustrate the struggle to control *P. juliflora* in the Middle Awash Basin and justify the recent designation of *P. juliflora* as a nationally declared, noxious alien species. It is ironic, however, that despite this declaration, seedlings of *P. juliflora* are currently being distributed to the north in Tigray and other dry parts of Ethiopia to rehabilitate degraded areas. Thus, even though the plant may serve a purpose for initial site protection, the challenge is to further manage the species so that it will not spread widely and have undesired ecological impacts. Regional policy coordination and awareness raising are vital needs to this end in Ethiopia.

**References**


Appendix A. Notes and Questionnaires
### Appendix 1.1. A preliminary checklist of flora at Allideghi Wildlife Reserve

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<th>Scientific Name</th>
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<td><em>Aristidia adoensis</em> Hochst.</td>
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43  Poaceae  Bothriochloa radicans (Lehm. (A. Camus
44  Poaceae  Digitaria rivae (Chiov.) Stapf.
45  Poaceae  Dactyloctenium scindicum Boiss.
46  Poaceae  Panicum coloratum L.
47  Poaceae  Sporobolus ioclades (Trin.) Nees
48  Poaceae  S. pellucidus Hochst.
49  Poaceae  Tetrapogon cenchriformis (A. Rich.) W.D.
          Clayton
50  Poaceae  Eragrostis ciliaris (All.) Vign. ex
          Janchen
51  Poaceae  Cenchrus ciliaris L.
52  Poaceae  Setaria pumila
53  Poaceae  Tragus racemosus
54  Poaceae  Lintonia nutans Stapf.
55  Poaceae  Cenchrus setigerus Vahl.
56  Poaceae  Dactyloctinum aegypticum (L.) Willd.
57  Poaceae  Drake-Brokmannia somalensis Stapf
58  Poaceae  Ischaemum afrum (J.F.Gmel.) Dandy
59  Portulacaceae  Portulaca quadrifida L.
60  Anticharis linearis (Benth.) Hochst. ex
      Scrophulariaceae  Aschers.
61  Rhamnaceae  Zizyphus spina-christi (L. Willd.
62  Solanaceae  Solanum coagulans Forssk.
63  Solanaceae  Solanum nigrum L.
64  Tiliaceae  Corchorus schimperi Cuf.
65  Tiliaceae  Corchorus trilocularis L.
66  Verbenaeanse  Chascanum marrubifolium Walp
67  Verbenaceae  Priva tenax Vend.
68  Zygophyllaceae  Tribulus terristrius L.

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<th>No.</th>
<th>Common Name</th>
<th>Scientific Name</th>
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<tr>
<td>1</td>
<td>Grevy’s Zebra</td>
<td>Equus grevyi</td>
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<td>2</td>
<td>Beisa oryx</td>
<td>Oryx gazelle</td>
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<tr>
<td>3</td>
<td>Soemmerring’s gazelle</td>
<td>Gazella soemmeringinig</td>
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<td>4</td>
<td>Gerenuk</td>
<td>Litocranius walleri</td>
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<td>5</td>
<td>Salt’s dikdik</td>
<td>Madoqua saltiana</td>
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<td>Phocoerus aethiopicus</td>
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<td>7</td>
<td>Lesser kudu</td>
<td>Teragelaphus imberbis</td>
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<td>Black backed jackal</td>
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<td>Abyssinian hare</td>
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<td>Anubis baboon</td>
<td>Papio anubis</td>
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<td>30</td>
<td>White bellied Africa hedgehogs</td>
<td>Atelerix sclateri</td>
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<td>31</td>
<td>Rats</td>
<td>Thryonomys spp</td>
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Appendix 2.1. Questions for focus group discussions and interviews

A. Questions for focus group discussions regarding views and attitudes of the people concerning habitat and wildlife conservation and sustainable resource use of the grassland for both livestock and wild animals.

Part I. Views of the people about their life at AWR

1. Name of the village?
2. How long have you been here?
3. How long will you stay here?
4. How do you live?
5. What are your biggest problems?
6. What do you see as the future?
7. How many people are living in this village?
8. Is the population of people and livestock growing, decreasing or stable?
9. Do you want to leave the area or stay?
10. What is your main source of income?
11. Do you have any secondary activity to get income? If yes, describe?

Part II. Views and attitudes of the people concerning sustainable resource use involving livestock and wildlife

1. How do you rate the value the Allideghi plain in terms of resources: High, medium, low?
2. For how long do you graze in the Allideghi plain (months)?
3. Do you move your livestock to other areas for grazing?
4. If yes, for how long and where?
5. Have you ever seen Grevy’s Zebra and other wild animals grazing with livestock in close proximity?
6. If yes, when (during dry or wet season)?
7. If no, why do you think they do not graze together?
8. Do you think the wild animals compete with the livestock for forage?
9. If yes, which one do you think is affected by the other?
10. How is the availability of forage during the last ten years? Increasing, decreasing, stable?
11. What do you think the reason could be?
12. How do you think is possible to maintain the area in good condition as a habitat for wild animals and as a source of livestock forage? How about having fewer animals but with good selling value?
13. Over the next few years, would you expect this area to get worse or remain about the same in terms of its use for grazing?

Part III: Attitudes of the local people towards habitat and wildlife conservation; their views about the management of Allideghi grassland and the role of the government

1. Do you think the presence of wild animals in this area has any benefit for the people? If yes/no, explain?
2. What is your view about Grevy’s Zebra? Are they important to you? If yes/no, explain?
3. How many Grevy’s Zebra would you estimate living in the Allideghi area?
4. Have there been noticeable changes in Grevy’s and other wild animals’ number over the past ten years? If yes, have the numbers increased, decreased or remain stable?
5. If there has been a change in numbers, what do you think are the causes?
6. Do you think Grevy’s Zebra and other wild animals should be protected in this area? If yes/no, explain why?
7. What do you suggest to the government to protect these wild animals?
8. Does wildlife cause you problems? If so, what types of problems?
9. What measures do you take to prevent the damage?
B. Questions for interviews for the respective natural resource bureau heads at
district, regional and federal levels regarding the current and future plans for
management of AWR and protection of Grevy’s Zebra.

Part I. At the district and regional level

1. What are the current management and policy measures to sustain Grevy’s Zebra
   in the area?

2. Do you have any plan at this level to conserve and manage AWR since it harbors
   the endangered Grevy’s Zebra and it needs urgent attention?

3. If yes,
   a. Short term:
   b. Long term:

4. If the following are not included in their plan, what is the perspective of the
   regional bureau concerning the following issues:
   a. Changing institutional framework so that the regional government will
      start protecting and managing the reserve,
   b. Changing the regulation for the area (i.e., use of the area for grazing and
      settlement) and design a new policy on the use of the area in the future
      which includes:
      i. Redefining the boundary of the reserve,
      ii. Gazetting the reserve,
      iii. Zonation which limits the pastoralists to use certain areas,
      iv. Establishing infrastructure and tourist facilities to get benefit from
          tourism,
      v. Developing a strategy for protection of Grevy’s Zebra and other
          wild animals while allowing livestock grazing in the area,
      vi. Plan for resettling the people to other area from the reserve.

5. How do you consider the concept of benefit sharing for the local communities to
   obtain their support in the conservation of the area?
6. Does the region have any plan for diversifying the income of the pastoralists so that their dependence on livestock will be minimized?

7. In the region’s short-term or long-term plan, is there any plan for developing water for the people in Allideghi area?

8. Do you have any plan in introducing modern livestock husbandry for Afar people in general and the communities in Allideghi and the surrounding areas in particular so that they can have fewer animals but with better selling value in order to minimize the impacts of livestock on the vegetation?

Part II. At the district and regional level

a) What is the current policy to protect endangered species as a national heritage?

b) What is the level of involvement of the federal government in the protection of endangered species such as Grevy’s Zebra?

c) If federal government is involved in such activities, do you have any plan at the federal level or together with the regional bureau to conserve and manage AWR since it harbors the endangered Grevy’s Zebra and it needs urgent attention?

d) If yes,
   a. Short term:
   b. Long term:

If the following are not included in their plan, what is the perspective of the federal bureau concerning the following issues:

   c. Changing institutional framework so that the federal government will involve in the management of this area because of the above reason. This includes establishing office, having the required skilled personnel and infrastructure development and others.
   d. Changing the regulation for the area and design a new policy on the use of the area.
   e. The fate of the people living in the area,
f. Redefining the boundary of the reserve,
g. Gazetting the reserve,
h. Zonation which limits the pastoralists to use certain areas,
i. Establishing infrastructure and tourist facilities to get benefit from tourism,

e) Developing a management plan/strategy for protection of Grevy’s Zebra and other wild animals and livestock grazing management.

Appendix 4.1. Description of *Prosopis juliflora*

*Prosopis juliflora* (Swartz) DC is one of 44 species of the genus *Prosopis* in the Fabaceae family. *Prosopis juliflora* (commonly called mesquite) is a thorny, semi-deciduous, evergreen tree native to Central and South America and the Caribbean (El-Keblawy and Al-Rawai 2007, Mwangi and Swallow 2005, Pasiecznik et al. 2001). Global concern about deforestation, desertification, and shortage of fuel wood in the 1970s and 1980s promoted the introduction of *P. juliflora* to new environments across the world (Mwangi and Swallow 2005). It has been widely introduced to Australia, Asia, the Middle East, the Caribbean, Latin America, the Virgin Islands, and Africa. Within Africa, major destinations have included Morocco, Senegal, Niger, Kenya, South Africa, Tanzania, Sudan, Uganda, Ethiopia, and Eritrea (ICRAF 2007, Pasiecznik et al. 2001).

This species usually grows up to 12 m in height, and with favorable conditions up to 20 m height. The main stem or trunk is green-brown, sinuous, and twisted. Thorns range from 1.2-5 cm long (ICRAF 2007, Le Houerou 2007). Leaves are bipinnate with 1-10 leaves per node. Flowers are small (4-6 mm long), gathered densely on racemes, and generally yellow, straw yellow, or yellow-white in color (Le Houerou 2007, Pasiecznik et al. 2001). Pods are indehiscent, straw-yellow in color, straight, and 15-20 cm long by 1-
1.5 cm wide. The hard seeds per pod vary from 10-20, with each being 2-8 mm long (Le Houerou 2007). Roots develop rapidly following germination up to a depth of 40 cm in eight weeks. A deep root system can be composed of one to three main tap roots which become very thick and can reach up to 35 m long until a permanent water source is reached. A lateral root system is composed of numerous lateral roots to quickly access rainfall. The lateral root system allows *P. juliflora* to strongly compete with herbaceous species (Le Houerou 2007, Pasiecznik et al. 2001).

The species primarily depends on ground water rather than surface water. It is referred to as a phreatophyte (Le Houerou 2007). It strongly tolerates drought, saline and sodic soils, and seasonal water-logging (ICRAF 2007). It propagates by seed, root cuttings, and grafting (ICRAF 2007). Seeds require scarification via heat, chemical, or mechanical means to penetrate the hard seed coat which otherwise prevents water uptake and subsequent germination (Pasiecznik et al. 2001). *Prosopis juliflora* grows in lowland areas with an altitude range of 0-1,500 m and mean annual temperatures and rainfall of 14–34°C and 50-1,200 mm, respectively (ICRAF 2007).

The species is a multipurpose tree and provides important economic benefits and valuable ecological services (Fagg and Stewart 1994, Bhojvaid et al. 1996, Pasiecznik et al. 2001). It can fix nitrogen and increase soil organic matter. On previously degraded soils, it can help reduce soil erosion and surface water runoff, and improve water infiltration and soil structure. The deep root system can take up nutrients and water from subsoil (Herrera-Arreola et al. 2007). *Prosopis juliflora* has been shown to improve soil fertility and reduce soil salinity. The branches and stems can serve as a source of fuel energy. Leaves and pods are supplemental feed for livestock, while pods can be boiled
and consumed by humans. The wood can be used as construction material for buildings and furniture.

*Prosopis juliflora* grows mainly in arid and semi-arid areas and has many important characteristics that enable it to be a successful invader in these ecosystems (Shiferaw et al. 2004, Herrera-Arreola et al. 2007). Its biological characteristics help this species survive in harsh environments where other tree species have failed to establish (Shiferaw et al. 2004). It is fast growing, highly aggressive, and can cause degradation in arid and semi-arid areas (Sharma and Dakshini 1998). Thus, the associated problems with this rapidly spreading species are a global phenomenon (Mwangi and Swallow 2004). *Prosopis juliflora* was listed as one of the IUCN’s new list of the 100 world’s worst invasive alien species in 2004 (ISSG 2006).

**References**


Appendix 4.2. Questions for focus group discussions and interviews.

Focus group discussion to explore the knowledge of pastoralists concerning the history of *P. juliflora* invasion and their attitude towards the increase in *Prosopis* in the area and on how *Prosopis* might be controlled

At the local level

1. Name of the village?
2. When do you settle at this village?
3. How many people are living in this village?
4. If the availability of forage is declining, do you think *Prosopis* is the major cause?
5. Do you know how and when *Prosopis* is introduced to Afar region and in the Allideghi plain?
6. What was your attitude when it first started to grow in this area?
7. Have you changed your attitude about the plant through time?
8. If yes, why?
9. Do you know how this plant is spreading in the grazing land?
10. Do you think livestock carry the seeds and disperse them in un-infested areas?
11. If yes, cattle, camel, sheep or goats?
12. Do you think restricting the movement of livestock from invaded areas would solve the problem?
13. Do you think *Prosopis* is a valuable plant or as an invasive plant?
14. If valuable, what are the uses?
15. If invasive, what are its impacts?
16. Do you think *Prosopis* is toxic for livestock?
17. How do you think *Prosopis* would be controlled?
18. Do you know about controlling methods such as mechanical removal, fire, and quarantine?
19. If fire is effective in controlling further dispersal of the plant, would you use it?
20. Which of these methods you like to use or not? Why?
21. Have you ever used *Prosopis* for livestock as supplemental forage and for fuel wood and charcoal making?
22. If you get the opportunity to have a grinding machine for pods, will you use it?
23. Do you need any training or help (incentives) to practice the controlling methods and technologies in order to control further dispersal of *Prosopis*.
24. If yes, for which methods?
25. Do you know any other woody plant which is taking over the grazing land like *Prosopis*?

At the regional level
1. Are policy and decision makers at regional level aware of the potential problems caused by *Prosopis* in the region in general and specifically in the Allideghi area where we have Grevy’s Zebra?
2. Was there any survey to determine how much area is affected by *Prosopis* invasion?
3. If yes, when and how much area is affected?
4. Does the region have any programs and plans for the control of *P. glandulosa*?
5. If yes,
   a. What are the programs?
   b. What are the future plans?
6. If there are some efforts of controlling *Prosopis* spread, which techniques were used and how successful are the techniques in controlling the plant?
7. What is the policy of the region towards the use of fire to control *Prosopis* and for management of the vegetation in general?
8. What is the capacity of the regional government to implement control techniques such as mechanical, fire, chemical and biological methods?
9. What will be the prospects for doing livestock quarantine before moving them to areas un-infested by *Prosopis* and fencing off animals from core *Prosopis* infested areas?

**EWCD - At the federal level**

1. Are policy and decision makers at federal level aware of the potential problems caused by *Prosopis* in Afar region in general and in Allideghi area in particular?
2. Is/will the federal government involve in controlling of *Prosopis* in the regions?
3. If yes, what is the capacity of the government to implement control techniques such as mechanical, fire, chemical and biological methods?
4. Are there any programs and plans for the control of *P. glandulosa* currently?
5. If yes,
   a. Programs
b. Plans

c. Major techniques to be used

6. What techniques are selected or exercised as appropriate for local control of *Prosopis*.

7. Is there any plan for livestock quarantine before moving animals from *Prosopis* infested to un-infested areas or from or to the country?

8. What policy measures are considered at the federal level needed to sustain effective control of *Prosopis*?

EARO - at the federal level

1. Are you aware of the potential problems caused by *Prosopis* in Afar region in general and in Allideghi area in particular?

2. Is/will the federal government involve in controlling of *Prosopis* in the regions?

3. If yes, what is the capacity of the government to implement control techniques such as such as mechanical, fire, chemical and biological methods?

4. Are there any programs and plans for the control of *P. glandulosa* currently?

5. If yes,
    a. Programs
    b. Plans
    c. Major techniques to be used

6. What techniques are selected or exercised as appropriate for local control of *Prosopis*.

7. How effective are these techniques?

8. Is there any plan for livestock quarantine before moving animals from *Prosopis* infested to un-infested areas or from or to the country?

9. What policy measures are considered at the federal level needed to sustain effective control of *Prosopis*?
Questions for Farm Africa and CARE

1. What are your major programs at Amibara District?
   Do you have programs on rangeland management? What are they?

2. How and when do you start the program on Prosopis control?
   a. What are the specific controlling methods you are using?

3. Do you think this program is successful? How? Explain. Which controlling methods are effective?

4. Do you have plan to use other methods which you have not tried now? If yes, what are these?

5. What is your view on chemical, fire, quarantine methods to control further invasion?

6. Did any members of your institution get training on the control of the invasion of Prosopis? If yes, what kind of training and number of trainees?

7. Do you know any other institutions or individuals involved in controlling/eradicating Prosopis? If yes, explain?

8. Does Prosopis have created any change on the weather condition if the area? If yes, describe the change?

9. Do you think areas which are invaded by Prosopis are lost or reclaimed?

10. As an institution, do you think Prosopis is an invader or a beneficial plant? How? Which one outweighs the other?

11. What are the potential uses of Prosopis other than the obvious ones: charcoal, firewood, and supplemental feed?

12. Do you think the introduction of Prosopis created any problem on human and animal health? If yes, what are they?

13. Do you know any plant species which resist the impact of Prosopis and grow in the area? If yes, what are they?

14. Do you know any disease or insect which affects survival of Prosopis seedling, shrub or tree? If yes, what are they?

15. Any other issues? Do you have any other information, any plans or programs for the future?
Questions for charcoal making associations (Melka Werer, Melka Sedi, and Allideghi)

1. When did you start making charcoal from *Prosopis*?
2. How many members do you have?
3. How much quintal are you making per day or per month?
4. How much income are you getting monthly?
5. How do you distribute the money among yourselves?
6. Do you have an account to deposit from this income?
7. At what age or height do you use *Prosopis* for charcoal?
8. How deep are you cutting the tree?
9. Are the *Prosopis* trees coming back after cutting this deep?
10. If yes, do you have other plan to control the growth of *Prosopis*?
11. What is the impact of drought on your work?
12. Are you cutting by selecting the older ones?
13. Have you noticed the growth of native plant species in areas you cleared for charcoal?
14. What is the status of *Prosopis* after you started charcoal making?
15. Do you think charcoal making will continue for the coming years?
16. If yes, why and for what purpose? To get income by charcoal making or for the control of *Prosopis*?
17. Do you think charcoal making will control *Prosopis*?
Appendix B. Complete Statistical Results for Chapter 2
Complete Statistical Results for Chapter 2

Logistic regression model results using R statistical package

Dry season

Gazelle
Deviance Residuals:
\[
\begin{array}{ccccc}
\text{Min} & 1Q & \text{Median} & 3Q & \text{Max} \\
-1.5834 & -0.8890 & -0.4355 & 1.1245 & 2.1922
\end{array}
\]

Coefficients:
\[
\begin{array}{cccccc}
\text{Estimate} & \text{Std. Error} & z \text{ value} & \text{Pr(>|z|)} \\
(Intercept) & -0.6662 & 0.5060 & -1.316 & 0.18801 \\
\text{Dist_village} & 0.7918 & 0.3096 & 2.557 & 0.01055 \ast \\
\text{Dist_livestock} & -1.6419 & 0.5388 & -3.047 & 0.00231 \ast\ast
\end{array}
\]

Ostrich
Deviance Residuals:
\[
\begin{array}{ccccc}
\text{Min} & 1Q & \text{Median} & 3Q & \text{Max} \\
-1.5250 & -0.8178 & -0.3852 & 0.8658 & 1.9362
\end{array}
\]

Coefficients:
\[
\begin{array}{cccccc}
\text{Estimate} & \text{Std. Error} & z \text{ value} & \text{Pr(>|z|)} \\
(Intercept) & -0.9237 & 0.5666 & -1.630 & 0.10304 \\
\text{Dist_village} & 0.8559 & 0.3609 & 2.371 & 0.01772 \ast \\
\text{Dist_livestock} & -2.4958 & 0.7559 & -3.302 & 0.00096 \ast\ast\ast
\end{array}
\]

Oryx
Deviance Residuals:
\[
\begin{array}{ccccc}
\text{Min} & 1Q & \text{Median} & 3Q & \text{Max} \\
-1.8782 & -0.6057 & -0.3607 & -0.1527 & 2.0613
\end{array}
\]

Coefficients:
\[
\begin{array}{cccccc}
\text{Estimate} & \text{Std. Error} & z \text{ value} & \text{Pr(>|z|)} \\
(Intercept) & -3.4225 & 0.8281 & -4.133 & 3.58e-05 \ast\ast\ast \\
\text{Dist_village} & 1.4253 & 0.4141 & 3.442 & 0.000578 \ast\ast\ast \\
\text{Dist_livestock} & -0.7027 & 0.5398 & -1.302 & 0.193058
\end{array}
\]

Zebra
Deviance Residuals:
\[
\begin{array}{ccccc}
\text{Min} & 1Q & \text{Median} & 3Q & \text{Max} \\
-1.88534 & -0.30976 & -0.14863 & -0.04712 & 2.47426
\end{array}
\]

Coefficients:
\[
\begin{array}{cccccc}
\text{Estimate} & \text{Std. Error} & z \text{ value} & \text{Pr(>|z|)} \\
(Intercept) & -6.8027 & 1.8513 & -3.674 & 0.000238 \ast\ast\ast \\
\text{Dist_village} & 2.3025 & 0.7457 & 3.088 & 0.002016 \ast\ast \\
\text{Dist_livestock} & -0.8153 & 0.8390 & -0.972 & 0.331150
\end{array}
\]
Wildlife (gazelle, ostrich, oryx, zebra, gerenuk and warthog)

Deviance Residuals:
Min  1Q  Median    3Q  Max
-2.0666 -0.9079  0.4222  0.7530  1.8746

Coefficients:
Estimate  Std. Error    z value  Pr(>|z|)
(Intercept)  0.5843     0.5704   1.024   0.305679
Dist_village  0.8943     0.3270   2.735   0.006240 **
Dist_livestock -2.1519     0.5975  -3.602  0.000316 ***

Livestock

Deviance Residuals:
Min  1Q  Median    3Q  Max
-1.7232 -0.7383 -0.5142  1.0004  1.9212

Coefficients:
Estimate  Std. Error    z value  Pr(>|z|)
(Intercept) 1.2277     0.6739   1.822   0.06847 .
Dist_village -0.7961     0.3273  -2.433  0.01499 *
Dist_wildlife -2.1052     0.7144  -2.947  0.00321 **

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Dry Season (when livestock migrate to cotton plantation)

Gazelle

Deviance Residuals:
Min  1Q  Median    3Q  Max
-1.8312 -0.9884 -0.6127  1.0659  1.8789

Coefficients:
Estimate  Std. Error    z value  Pr(>|z|)
(Intercept)  0.9122     0.6196   1.472   0.14099
Dist_village  0.5575     0.3019   1.847   0.06476 .
Dist_livestock -1.2016     0.4237  -2.836  0.00457 **

Ostrich

Deviance Residuals:
Min  1Q  Median    3Q  Max
-1.4685 -0.8761 -0.6457  1.0985  1.8277

Coefficients:
Estimate  Std. Error    z value  Pr(>|z|)
(Intercept)  0.07425     0.60633  0.122   0.9025
Dist_village  0.58808     0.32298  1.821   0.0686 .
Dist_livestock -1.06206     0.43093  -2.465   0.0137 *
## Oryx

Deviance Residuals:

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<th>Max</th>
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<tr>
<td>-1.6302</td>
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Coefficients:

| Estimate | Std. Error | z value | Pr(>|z|) |
|----------|------------|---------|---------|
| (Intercept) | -1.3459   | 0.6400  | -2.103  | 0.03548 * |
| Dist_village | 1.0539    | 0.3334  | 3.161   | 0.00157 ** |
| Dist_livestock | -0.6161  | 0.3782  | -1.629  | 0.10331 |

## Zebra

Deviance Residuals:

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<td>-0.6932</td>
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Coefficients:

| Estimate | Std. Error | z value | Pr(>|z|) |
|----------|------------|---------|---------|
| (Intercept) | -1.9609   | 0.9397  | -2.087  | 0.0369 * |
| Dist_village | 0.6575    | 0.5928  | 1.109   | 0.2674   |
| Dist_livestock | -1.0044  | 0.7276  | -1.380  | 0.1675   |

## Wildlife (gazelle, ostrich, oryx, zebra, gerenuk and warthog)

Deviance Residuals:

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Coefficients:

| Estimate | Std. Error | z value | Pr(>|z|) |
|----------|------------|---------|---------|
| (Intercept) | 1.7763    | 0.6902  | 2.574   | 0.01006 * |
| Dist_village | 0.5450    | 0.2917  | 1.868   | 0.06175 . |
| Dist_livestock | -1.1558 | 0.4130  | -2.799  | 0.00513 ** |

## Livestock

Deviance Residuals:

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<td>-0.6051</td>
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Coefficients:

| Estimate | Std. Error | z value | Pr(>|z|) |
|----------|------------|---------|---------|
| (Intercept) | -1.6051   | 0.9359  | -1.715  | 0.0864 . |
| Dist_village | -1.1259  | 0.8026  | -1.403  | 0.1607   |
| Dist_wildlife | -0.4256  | 1.1394  | -0.374  | 0.7088   |

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Wet season

**Gazelle**

Deviance Residuals:

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Coefficients:

|                      | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | 0.4801   | 1.0846     | 0.443   | 0.6580   |
| Dist_village         | 0.4868   | 0.4647     | 1.047   | 0.2949   |
| Dist_livestock       | -1.2050  | 0.5766     | -2.090  | 0.0366 * |
| Dist_temp_set        | -0.1881  | 0.2705     | -0.696  | 0.4867   |
| Dist_temp_water      | -0.3041  | 0.3576     | -0.850  | 0.3951   |

**Ostrich**

Deviance Residuals:

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Coefficients:

|                      | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -0.4494  | 1.0084     | -0.446  | 0.65586  |
| Dist_village         | 0.8084   | 0.4766     | 1.696   | 0.08986 .|
| Dist_livestock       | -1.7038  | 0.6238     | -2.731  | 0.00631 **|
| Dist_temp_set        | 0.1382   | 0.2578     | 0.536   | 0.59179  |
| Dist_temp_water      | -0.1856  | 0.3451     | -0.538  | 0.59066  |

**Oryx**

Deviance Residuals:

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Coefficients:

|                      | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -0.5815  | 1.0941     | -0.531  | 0.5951   |
| Dist_village         | 1.0783   | 0.5463     | 1.974   | 0.0484 * |
| Dist_livestock       | -1.3689  | 0.6134     | -2.232  | 0.0256 * |
| Dist_temp_set        | -0.2531  | 0.2780     | -0.910  | 0.3627   |
| Dist_temp_water      | -0.1409  | 0.3817     | -0.369  | 0.7120   |

**Zebra**

Deviance Residuals:

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Coefficients:

|                      | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -2.4107  | 1.4814     | -1.627  | 0.104    |
| Dist_village         | 0.3502   | 0.6257     | 0.560   | 0.576    |
| Dist_livestock       | -0.5795  | 0.7933     | -0.730  | 0.465    |
| Dist_temp_set        | 0.1160   | 0.3639     | 0.319   | 0.750    |
| Dist_temp_water      | -0.1130  | 0.5106     | -0.221  | 0.825    |
Wildlife (gazelle, ostrich, oryx, zebra, gerenuk and warthog)

Deviance Residuals:

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Coefficients:

|                                | Estimate | Std. Error | z value | Pr(>|z|) |
|--------------------------------|----------|------------|---------|---------|
| (Intercept)                    | 1.1758   | 0.9232     | 1.274   | 0.2028  |
| Dist_village                   | 1.1580   | 0.5022     | 2.306   | 0.0211  *|
| Dist_livestock                 | -1.5677  | 0.6360     | -2.465  | 0.0137  *|
| Dist_temp_set                  | -0.1679  | 0.2349     | -0.715  | 0.4749  |
| Dist_temp_water                | -0.3900  | 0.3514     | -1.110  | 0.2672  |

Livestock

Deviance Residuals:

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Coefficients:

|                                | Estimate | Std. Error | z value | Pr(>|z|) |
|--------------------------------|----------|------------|---------|---------|
| (Intercept)                    | 2.3178   | 1.2232     | 1.895   | 0.0581  .|
| Dist_village                   | -1.1700  | 0.4667     | -2.507  | 0.0122  *|
| Dist_wildlife                  | -1.8878  | 0.7592     | -2.487  | 0.0129  *|
| Dist_temp_set                  | -0.3263  | 0.2885     | -1.131  | 0.2581  |
| Dist_temp_water                | 0.2120   | 0.3704     | 0.573   | 0.5670  |

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Appendix C. Complete Statistical Results for Chapter 3
Complete Statistical Results for Chapter 3

Effects of livestock grazing on standing biomass, species richness, productivity, and utilization

Three-way ANOVA results of the linear mixed model for standing biomass

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<th>p-value</th>
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Grass biomass

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Herb biomass

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Two-way ANOVA results of the linear mixed model for species richness

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Grass species

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Forb species

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One-way ANOVA results of the linear model for productivity

Total productivity

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Grass productivity

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Herb productivity

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<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

One-way ANOVA results of the linear model for utilization

Total biomass utilized

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Grass biomass utilized

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Herb biomass utilized

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<tr>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
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<tbody>
<tr>
<td>Grazing</td>
<td>2</td>
<td>5775.4</td>
<td>2887.7</td>
<td>34.372</td>
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<tr>
<td>Residuals</td>
<td>9</td>
<td>756.1</td>
<td>84.0</td>
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Appendix D. Complete Statistical Results for Chapter 4
Complete Statistical Results for Chapter 4

Impacts of different size classes of *P. juliflora* on herbaceous vegetation

Two-way ANOVA results of the linear mixed model for changes in species composition

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>3149.1305</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment</td>
<td>3</td>
<td>14</td>
<td>0.0000</td>
<td>1</td>
</tr>
<tr>
<td>Type(grass/herb)</td>
<td>1</td>
<td>14</td>
<td>208.5792</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment:Type</td>
<td>3</td>
<td>14</td>
<td>237.8589</td>
<td>&lt;.0001</td>
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</tbody>
</table>

Two-way ANOVA results of the linear mixed model for changes in species composition

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>3941.644</td>
<td>&lt;.0001</td>
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<tr>
<td>Treatment</td>
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<td>14</td>
<td>121.764</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Type</td>
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<td>14</td>
<td>422.123</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment:Type</td>
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<td>14</td>
<td>48.627</td>
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Two-way ANOVA results of the linear mixed model for changes in plant cover

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</thead>
<tbody>
<tr>
<td>(Intercept)</td>
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<td>14</td>
<td>1026.0233</td>
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<tr>
<td>Treatment</td>
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<td>14</td>
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<tr>
<td>Type</td>
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<td>14</td>
<td>131.7590</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment:Type</td>
<td>3</td>
<td>14</td>
<td>78.5075</td>
<td>&lt;.0001</td>
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</tbody>
</table>

Two-way ANOVA results of the linear mixed model for changes in litter and bare ground cover

<table>
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<tr>
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<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>3010.652</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment</td>
<td>3</td>
<td>14</td>
<td>163.986</td>
<td>&lt;.0001</td>
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<tr>
<td>Type(litter/bare ground)</td>
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<td>3239.981</td>
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<tr>
<td>Treatment:Type</td>
<td>3</td>
<td>14</td>
<td>263.269</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
PLATES
Plate 3.1. The 3 x 3 m exclosure for the determination of aboveground standing-crop biomass, productivity, utilization and species richness of the herbaceous layer at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005.
Plate 3.2. The severely grazed area near the settlement and watering point which has <10% basal vegetation cover at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005.
Plate 3.3. The heavily grazed area which has ≥ 25% basal vegetation cover at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005.
Plate 3.4. The moderately grazed area which has $> 50\%$ basal vegetation cover at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005.
Plate 3.5. The ungrazed (control) area which has not been grazed for 8 years at Allideghi Wildlife Reserve (AWR), Ethiopia, during 2005.
Plate 4.1. Seedlings of *P. juliflora* along livestock trails at Allideghi Wildlife Reserve (AWR), Ethiopia.
CURRICULUM VITAE

Almaz Tadesse Kebede

EDUCATION

2009  **PhD, Range Science**, Utah State University, Logan, UT

1997  **MSc, Biology**, Addis Ababa University, Addis Ababa, Ethiopia

1989  **BSc, Biology**, Asmara University, Asmara, Eritrea

PUBLICATIONS


EXPERIENCE

2003 – 2008

PhD candidate in Range Science program, College of Natural Resources, Utah State University, Logan, Utah. The focus of my dissertation research was to determine the impact of pastoralism and vegetation change on the sustainability of grassland in a wildlife reserve, Allideghi Wildlife Reserve, Ethiopia which is internationally significant for its population of Grevy’s Zebra.

October 1998 - April 2000

Research and Veterinary Service Team Leader, Ethiopian Wildlife Conservation Organization (EWCO), Addis Ababa, Ethiopia. As a team leader the responsibilities include human resources management, organizing and conducting researches on wildlife, designing and facilitating research projects, involving in resource identification and designing management plan for the national parks and wildlife sanctuaries.


Botanist, EWCO, Addis Ababa, Ethiopia. As a botanist the responsibilities include to conduct botanical survey, participate in wildlife monitoring activities, collecting and identifying plant specimens from national parks and establishing herbarium.

September 1993 – March 1997

MSc Graduate Student, Addis Ababa University, Addis Ababa, Ethiopia. The focus of the research was evaluating the biomass production and nutrient status of three dominant grass species in Awash National Park, Ethiopia in different season of the year.

September 1989- August 1993
Field biologist, Awash National Park, Awash, Ethiopia. As a field biologist the major responsibilities were conducting wildlife census to know the status of wild animals specially those species which needs special attention like Swayne's Hartebeest, participating in the preparation of the management plan of the park, plant collection, identification and establishment of herbarium.

Major short-term trainings/conferences/workshops/expeditions attended

1. 18th annual meeting: Society for Conservation Biology: July 30th to August 2nd, 2004 - New York, New York, USA
2. Biodiversity Support program (BSP) Pan-African Workshop on Armed Conflict and the Environment; Victoria Falls, Zimbabwe, April 2001