Federal Ministry
for Economic Cooperation
and Development

Managing *Prosopis Juliflora* for better (agro-) pastoral Livelihoods in the Horn of Africa

Proceedings of the Regional Conference

May 1 - May 2, 2014, Addis Ababa, Ethiopia

Published by:

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

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Regional Conference on Managing *Prosopis juliflora* for better (agro-)pastoral Livelihoods in the Horn of Africa

May 1 - May 2, 2014, Desalegn Hotel, Addis Ababa, Ethiopia

Encroachment of Invasive Alien Species is a globally common phenomenon and often has detrimental effects on rural households in developing countries. *Prosopis juliflora* is one of the world's worst invasive alien species causing severe environmental degradation to the arid and semi-arid lowlands of the Horn of Africa and threatening the livelihood and thus food security of pastoral and agro-pastoral communities. Today, many countries such as Ethiopia, Sudan, Kenya, Eritrea, and Somalia are heavily affected. In Ethiopia the *Prosopis juliflora* invasion has been growing out of control for already more than a decade. In Ethiopia's Afar Region, with 90% of the Afar population being (agro-) pastoralists and their livelihood mainly depending on livestock production using rangeland, more than 700,000 ha have already been invaded as *Prosopis juliflora* rapidly spreads across both pastoral and agricultural lands. The ecological consequences have been devastating since rangeland areas are degraded due to severe losses in ecological functions and forage grass productivity has declined drastically. The major impact in economic terms has been a massive impoverishment, especially among cattle pastoralists whose animals depend on the rich floodplain grasses along the Awash River that have almost completely been replaced by *Prosopis juliflora.* The spread of *Prosopis juliflora* also influences social and environmental aspects beyond invaded areas. Pastoralists who lost their grazing land have to search for new livelihood opportunities or move to new grazing areas, which raises the risk of land conflicts with other pastoralists and farmers. Furthermore, increasing livestock densities on the remaining pasture land trigger continuing land degradation. Under these conditions, the vulnerability of pastoralists has increased and drought induced acute food insecurity has been replaced by chronic food insecurity for large parts of the pastoral population.

The complex phenomenon of *Prosopis juliflora* invasion has not been addressed sufficiently yet, even though today it seriously challenges (agro-)pastoralism as well as irrigated agriculture implying a multitude of social, economic and environmental threats affecting the overall development in the Horn of Africa. Therefore, the GIZ Sectoral Project for Rural Development, on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), financed a comprehensive research study to assess the social, economic and ecological impacts of *Prosopis juliflora* invasion using the example of Ethiopia's Afar Region. The research was carried out between October 2013 and April 2014 by an international research team led by the University of Hohenheim (Prof. Dr. Regina Birner and Dr. Anna C. Treydte) and the University of Bonn (Prof. Dr. Detlef Müller-Mahn and Dr. Simone Rettberg), Germany.

In May 2014, GIZ, Mekelle University (Ethiopia), the UNESCO-IHE Institute for Water Education (Netherlands) and the Spate Irrigation Network Foundation jointly organized a regional conference on *Prosopis juliflora* for the Horn of Africa. The conference, funded by BMZ, IFAD and UNESCO-IHE, presented the BMZ commissioned multi-disciplinary research results from Ethiopia's Afar Region, and also invited other researchers, academics and practitioners from various countries and backgrounds as well as policy makers, development agents and community representatives from the region to present their work on *Prosopis juliflora*, share well documented experiences, practices, and lessons learned on managing *Prosopis juliflora* (and other invasive species), and to finally discuss the way forward for an integrated and successful *Prosopis juliflora* management in the Horn of Africa.

The conference proceedings summarize the presentations held and the results of the fruitful discussions during the 2-day conference. The conference presentations as well as further information and material on *Prosopis juliflora* can be downloaded from http://agriwaterpedia.info/wiki/Prosopis.

We would like to thank all participants for their interest, inputs and active participation as well as GIZ Ethiopia for their support in organizing the research work and the conference.

For the organizing committee

Nadine Guenther and Elisabeth van den Akker	GIZ
Eyasu Yazew and Tesfa-alem G. Embaye	Mekelle University
Abraham Mehari Haile	UNESCO-IHE

1. The spread of *Prosopis juliflora* in the wetlands of the Middle Awash Basin

Simone Rettberg, University of Bonn, Germany

1.1 Introduction

For many decades the problem of land degradation has dominated the public debate in Ethiopia, informing a variety of governmental and international development and policy initiatives that aimed at the conservation of natural resources through soil and water management (KEELEY & SCOONES 2003). In this regard one of the activities of the Derg military regime during the 1970s and early 1980s was the intentional introduction of *Prosopis juliflora* to the Ethiopian lowlands. This was part of its environmental rehabilitation campaign in which the planting of *Prosopis juliflora* was conceived as an afforestation measure to halt desertification processes in dryland areas (RETTBERG & MÜLLER-MAHN 2012). This development intervention had massive unforeseen socio-ecological consequences (as can be seen in most contributions in these conference proceedings) due to fact that *Prosopis juliflora* increasingly out-competed the native vegetation, taking over valuable grasses, shrubs and trees, leading to a substantial shift in the vegetation composition.

This invasion process affected mainly the best areas in terms of agro-ecological conditions, the wetlands, large floodplain areas (Afar: Kallo) along the Awash River, where seasonally flooded fertile soils provided abundant grazing opportunities for pastoralists as well as a good potential for irrigation agriculture (Fig.1). Therefore, it was these areas where the imperial regime of Haile Selassie and later the Derg regime decided to establish irrigated cotton farms, ignoring the customary land rights of the local Afar clans who had been using this area as dry season grazing area and drought retreat for centuries. When local administrators were ordered to plant *Prosopis juliflora* seedlings around the state farms and in the few permanent settlements in the vicinity of these farms, it was mainly for the benefit of governmental agriculture and the settled population (mostly migrant workers from the highlands) who were supposed to benefit from an improved microclimate, e.g. less wind and more shade, and from improved soils that might raise future cotton yields. From the beginning, the transfer of the exotic *Prosopis juliflora* plant to the Afar lowlands was not intended to improve the livelihood of mobile Afar pastoralists, the main inhabitants of the area, whose mobile livelihood and assumed 'unsustainable land use practices' were considered by the government to be the main source of the problem of land degradation. The introduction of *Prosopis juliflora* in the Afar Region of Ethiopia exemplifies how an external intervention of natural resource management in dryland areas, although well-meant at least for part of the population during the time of its introduction, turned out to be one of the main drivers for a socio-ecological disaster that has been unfolding in the Afar Region over the last 30 years. Cynically though, it is the mobile pastoralists who were the ones most affected by this and whose vulnerability to drought increased tremendously.

1.2 Social and ecological drivers of invasion: The case of Baadu

Taking a broader perspective which contextualizes the spread of *Prosopis juliflora* in a wider scenario of risks, including additional problematic political-economic developments in the region, the case highlights

that the drivers of invasion can't only be seen in the biological dynamics and the invasiveness of the plant but also in an increased invadability of certain areas like Baadu, a flat seasonally inundated alluvial plain surrounded by higher-lying hills and mountains with an average annual rainfall of 450 mm.

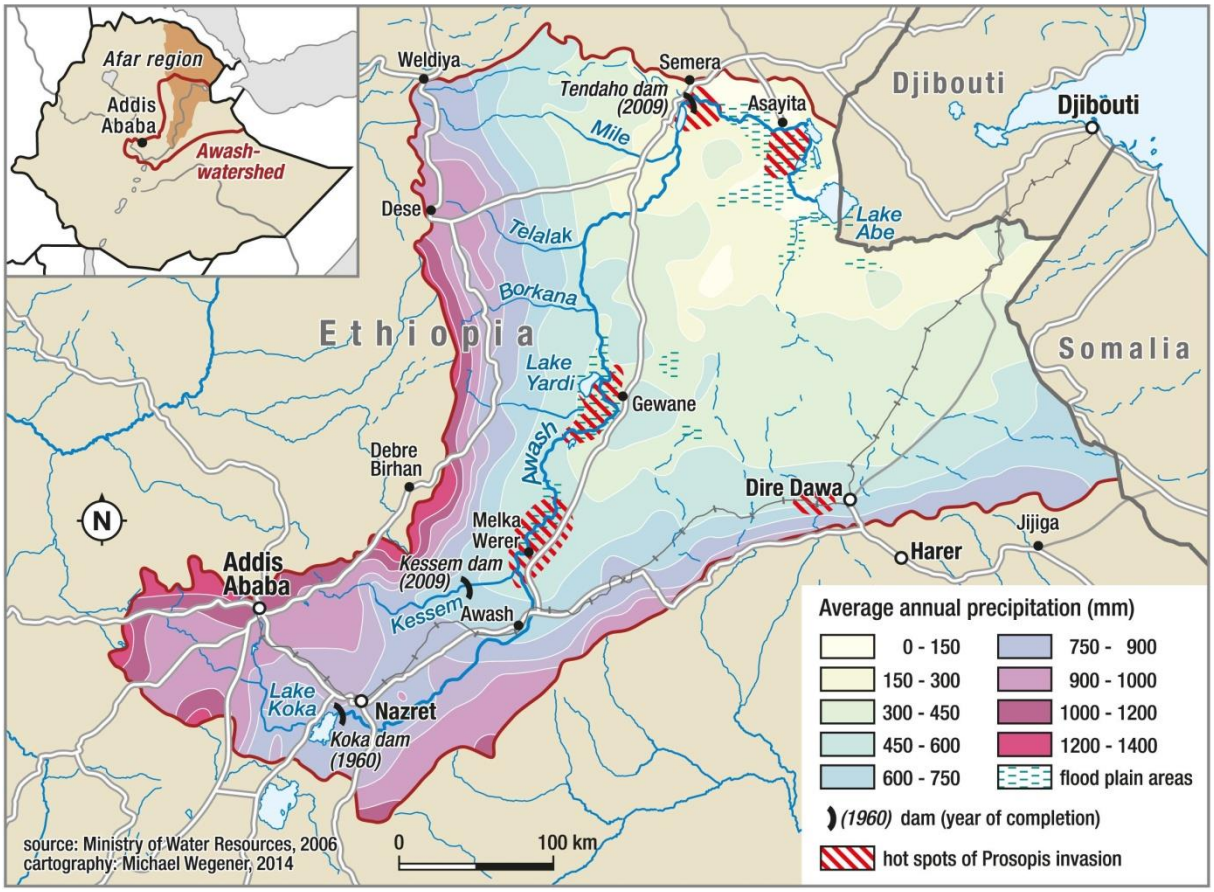

Figure 1: *Prosopis juliflora* invaded areas within the Awash Basin

The invadability of Baadu, in the sense of an increased susceptibility to *Prosopis juliflora* invasion, is closely linked with two factors which contributed significantly to additional land losses for the pastoralists next to the spread of *Prosopis juliflora*: 1) the violent conflict with the Issa pastoralists, a Somali sub-clan, and 2) the expansion of irrigation agriculture along the Awash River. Between 1940 and 1980, the year of *Prosopis juliflora* introduction to Baadu, the better-armed Issa had pushed the Afar from most of the wet season grazing areas which were stretching up to Dire Dawa to the east (Rettberg, 2009). Therefore, in 1980, their mobility, the key resource for pastoralists, was already severely limited and the herders were moving with their animals mostly within Baadu and the surrounding hills, but not much further due to fear of Issa. This conflict-induced land losses and reduced animal movements between dry and rainy season areas fostered soil degradation due to overgrazing and favored the growth of *Prosopis juliflora* as the plant tends to infest areas that have been overgrazed and lack a healthy woody and herbaceous layer component (see proceedings Treydte et al.). Furthermore the relatively high number of animals within the few remaining grazing areas in Baadu increased the dissemination rates of the newly introduced *Prosopis juliflora* seeds.

The grazing areas in Baadu, traditionally used as dry season grazing, were not only under pressure due to the conflict and subsequent overstocking, but also due to the fact that the Derg regime had started to establish several large-scale state and cooperative farms during the 1970s, several years before the introduction of *Prosopis juliflora* (Fig.2). The establishment of irrigation farms and hydraulic infrastructure reduced dry season grazing areas, altered flood regimes and contributed to a salinification of the soils, conditions

which fostered the spread of the salt-tolerant *Prosopis juliflora* plant after 1991. When most of these farms were left fallow due to the collapse of the Derg regime *Prosopis juliflora*, the previous fence and wind-break of these farms colonized the farm area and continued to spread from there. With the lack of maintenance of hydraulic infrastructure on the abandoned farms the dikes and dams along the Awash River have been breaking repeatedly since the mid 1990s, diverting the river in several directions away from the main course. The uncontrolled floodwaters are a major agent for the spread of *Prosopis juliflora* seeds to new areas. Nowadays floods have become a more frequent hazard in Baadu than droughts with more severe impacts than in the past since more and more impoverished pastoralists have started with small-scale irrigation agriculture within the last 10 years. Even this year, 2014, large areas within Baadu were inaccessible due to flood waters and farms and houses were destroyed. On the other hand the main river course sometimes runs the risk of falling dry due the frequent changes of the river course and the increased irregularity of flood waters. This situation explains why pastoralists rated the diminishing volume of the Awash River as problematic as the spread of *Prosopis juliflora* (see proceedings Hamedou).

The historical and socio-political contextualization of the spread of *Prosopis juliflora* reveals that social and ecological issues are highly interrelated leading to a massive disturbance of grasslands and forests along the Awash River as well as to a severe livelihood crisis for Afar pastoralists. Currently around 40% of the wetlands of Baadu are covered by *Prosopis juliflora* and therefore lost as fodder resource for animals (Ayanu et al., 2014) leading to the question how people in Baadu deal with this critical situation in which mobile pastoralism is about to collapse.

1.3 *Prosopis juliflora* as trigger for land use change

When more and more of the previous dry season pastures were taken over by *Prosopis juliflora* in the 1990s and the first decade of the 20th century, while at the same time most wet season pastures were inaccessible due to the risk of violent clashes with the Issa who had settled on the occupied land, the available grazing resources in Baadu could not sustain all the 21 clans that had their clan territories in the area. Land became increasingly a scarce resource and in order to make use of the *Prosopis juliflora* invaded areas clan elders and leaders decided to lease out these areas of communal clan-based grazing land to private agricultural investors. Therefore, the increase of large-scale agriculture by mostly non-Afar investors has to be seen as an adaptation strategy of the Afar pastoral elite to benefit from the *Prosopis juliflora* invaded areas which they could not use otherwise due to lack of capacity. A more recent activity to make use out of *Prosopis juliflora* is charcoal trade. This has become an increasingly important and highly profitable activity for some Afar in Baadu (see proceedings Datona) although so far most Afar don't benefit from it.

The drought of 2003 killed most of the cattle who had already lost large part of their fodder base (grasslands) due to *Prosopis juliflora* and who could neither resist this drought nor recover from it in the following. It was after 2003 that many people were destitute and forced to diversify their livelihood and to generate income to make up for the lack of milk, the main food item before. Small-scale agriculture, an unknown activity for most pastoralists in Baadu, and sedentarization processes have increased significantly since then (Fig.2). In the process pastoralist kept on clearing *Prosopis juliflora* from their farms. Currently all households in Baadu have diversified their livelihood significantly. There is a complementary combination of livelihood activities within the household and within the clan so that forms of settled agro-pastoralism, other income generating activities and mobile pastoralism complement each other (Müller-Mahn et al., 2012).

While these non-pastoral activities opened up new economic possibilities they were also linked with certain negative side effects. The monetarization of the economy, especially the commodification and

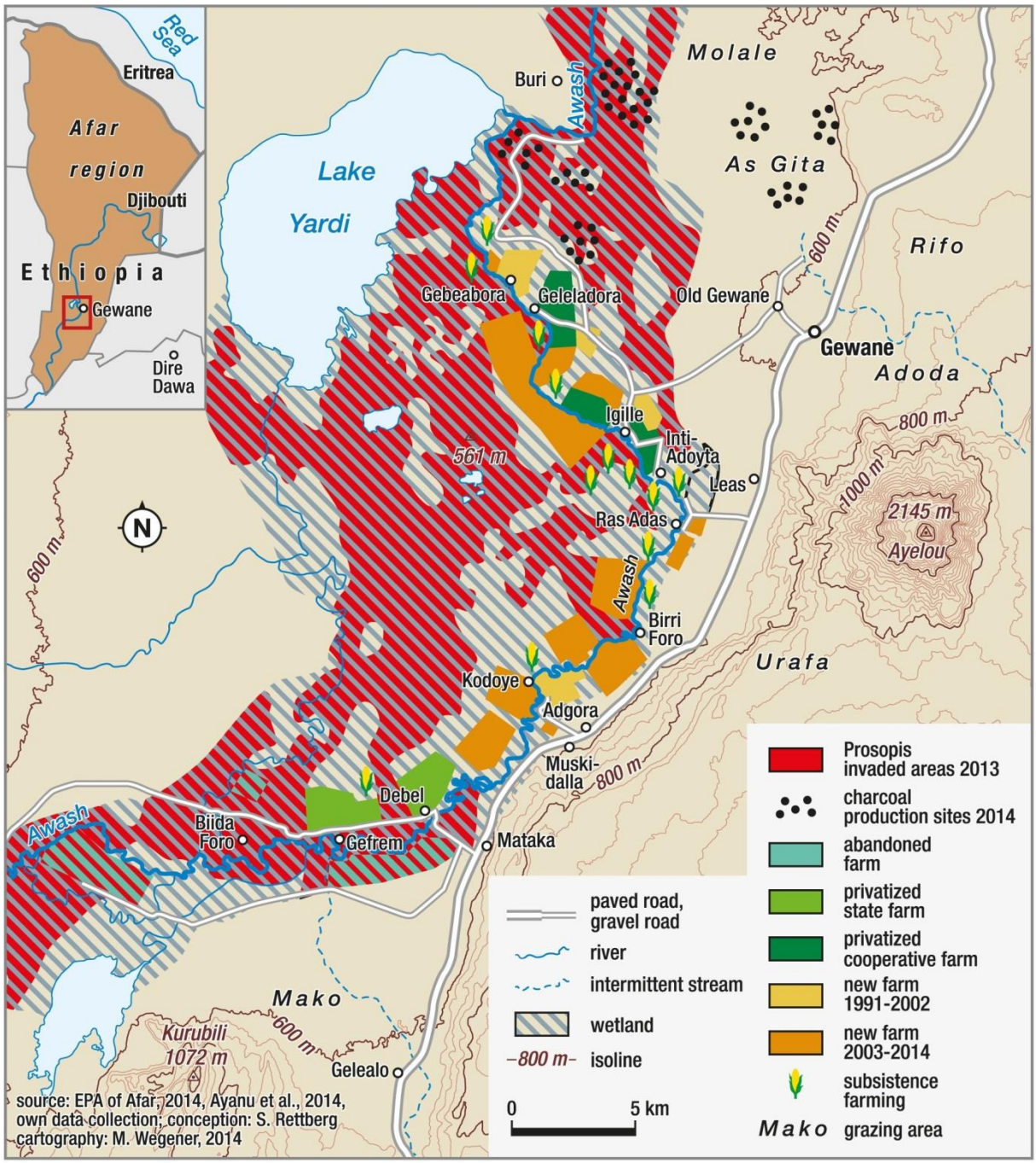

Figure 2: Land use change in Baadu

privatization of natural resources like land and forests, challenges the social values and familiar patterns of identification of the Afar pastoral society which build on solidarity and reciprocity (Rettberg, 2010). Indigenous institutions have become weak in the process and there is a growing leadership crisis in the region. Conflicts about land have become common and land rights are frequently violently contested between Afar clans.

Next to these social problems also ecological problems have increased in the process of land use change. Deforestation has become a major problem in a situation of widespread poverty where many people don't respect anymore the local rules for the management of natural resources and where not only *Prosopis juliflora* but other valuable trees are illegally cut. Secondly, the wetlands of Baadu which played a vital role

for the survival of the pastoralists in the past have been largely destroyed due to increasing human pressure of different user groups in the name of economic development. Next to the intentional introduction and unintentional invasion of *Prosopis juliflora*, water pollution due to pesticides and insecticides is a growing concern (one of the main problems mentioned by pastoralists). Additionally, the construction of dams and dykes has altered the water regime and pattern of discharge which increased the risks of uncontrolled floods in some areas while other areas are getting drained.

1.4 Conclusion

Unfortunately the Ethiopian government did not value the importance of these wetlands so far either due to lack of knowledge or ignorance. There is no comprehensive policy or strategy neither for the management of *Prosopis juliflora* nor more generally for the management of wetlands. Studies and pilot projects were implemented; calls for a controlled management of invasive species were voiced but no institution was given the responsibility and necessary resources to deal with the ongoing critical changes in the wetlands of Baadu (proceedings Chekol). Dealing with the invasion of *Prosopis juliflora* should be embedded into an integrated plan for the management of wetlands that is based on clear rules and regulations and a strong institution enforcing these rules. Unless the invasion of *Prosopis juliflora* is understood as one among several problems in a wider scenario of risks which include ecological dynamics as well as social threats and unless the current ongoing economic developments are considered as one of the main pressures and risks for the ecosystem and its' inhabitants any external management intervention will lack sustainability. It needs to be acknowledged that *Prosopis juliflora* is actually not the root cause for the destruction of the wetlands but a symptom of misguided environmental management, something which should be prevented in the future.

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2. Quantitative Assessment of Invasion of *Prosopis juliflora* in Baadu, Afar Regional State of Ethiopia

Yohannes Zergaw Ayanu, University of Bayreuth, Germany

2.1 Introduction

The increasing human population has put pressure on natural resources and resulted in severe land degradation in Ethiopia. Moreover, drought and harsh environmental conditions in some parts of the country affected the livelihood of the people. The middle and lower parts of the Awash River Basin that are parts of the Afar Regional State of Ethiopia have been economic sources of Ethiopia where large-scale state farms are located. Irrigation capacity of the Awash River provides ample potential for large scale commercial farms. Besides, the area is home to Afar pastoralists whose livelihood is largely dependent on livestock production that basically relies on the rangelands along the Awash River and the seasonally flooded low lands.

Pressure on the natural resources in the area continues to increase due to increased population and expansion of large-scale state and private farms. In the past decades, there is a remarkable decrease in pasture lands in the area that threatened the livelihood of the Afar pastoralists. During the last three decades, the Afar pastoralists of Northeast Ethiopia have been faced with accelerated social and ecological change which was linked to processes of massive impoverishment and increasing vulnerability. Especially the loss of extensive grazing areas and nomadic mobility resulted in chronic food insecurity (Rettberg, 2010). Expansion of large-scale farms by new private investors has also resulted in displacement of the pastoralists in the basin. There is strong pressure also on the hydrological resources in the Awash Basin which came from competing water uses for irrigated large scale farms as well as increasing number of dams for hydroelectric power generation. The limited area covered by lakes and marshy land is also shrinking from time to time.

Besides the aforementioned problems, deforestation in the past resulted in degradation of the natural ecosystems in the area, challenging the sustainability of resource use and management in the region. In the past, attempts have been made by the government to regulate soil erosion problems in the floodplains of the Awash River. One of these attempts is introduction of fast growing species such as *Prosopis juliflora* to restore degraded lands and protect against soil erosion. *Prosopis juliflora* was introduced to the arid and semi-arid regions of Ethiopia in the 1970s and 1980s mainly for the purpose of soil and water conservation (Tegegn, 2008).

Although *Prosopis juliflora* was introduced on purpose for regulating wind speed and for regulating water-induced soil erosion, it has developed unforeseen negative outcomes leading to loss of enormous ecosystem services (Ayanu et al.). Recently, spreading of this invasive plant species has become a major problem threatening the livelihoods of people in the Awash Basin, particularly the middle and lower Awash Region such as Baadu, Amibara and Dubti. After being well-established in the introduction sites, the species turned

to be invasive and spread to larger areas and it is continuously spreading at an alarming rate. Therefore, quantifying and mapping the spatial extent of the spread of *Prosopis juliflora* is essential to understand the extent of damage it causes and explore applicable management options.

In this study, the area of *Prosopis juliflora* invasion in Baadu, a source of dry season pasture for Afar pastoralists, was quantified and mapped using combination of satellite remote sensing data and field surveying. The temporal changes of *Prosopis juliflora* were assessed based on the findings in our recent paper in the study area, Ayanu et al. Further research questions regarding spreading patterns of the species to other parts of Awash Basin were identified and discussed.

2.2 Methodology

Study site

The study site, Baadu, is located in the middle Awash River Basin of Ethiopia in the Afar Regional State. The Awash River Basin is located in the North-Eastern part of Ethiopia partly in the Afar Region and partly in Oromia Region extending up to the capital city of Ethiopia, Addis Ababa (Figure 1).
The Awash River Basin has a total area of 113,709 km2. The Awash River drains through the Rift Valley plains with the limits of 8o30o to 12oN latitude and 38o to 43o30oE longitude. The basin ranges from 3600 m in the western highlands to 250 m above sea level in Lake Abhe on the border between Ethiopia and Somalia where the river terminates. The mean annual rainfall ranges from below 150 mm in the Afar depressions to 1200 mm in the highlands. The Awash River originates as a small spring in the central highlands of Oromia. Its major tributaries like Kessem originate from the northwestern plateau. Rivers in the eastern plateau are seasonal and disappear in the rift during dry seasons. The major lakes in the area are Beseka, Gamari, Afambo and Abhe covering the rift floor and Hayq and Ardibo are lakes without outflows in the highlands (Ayenew & Legesse, 2007).

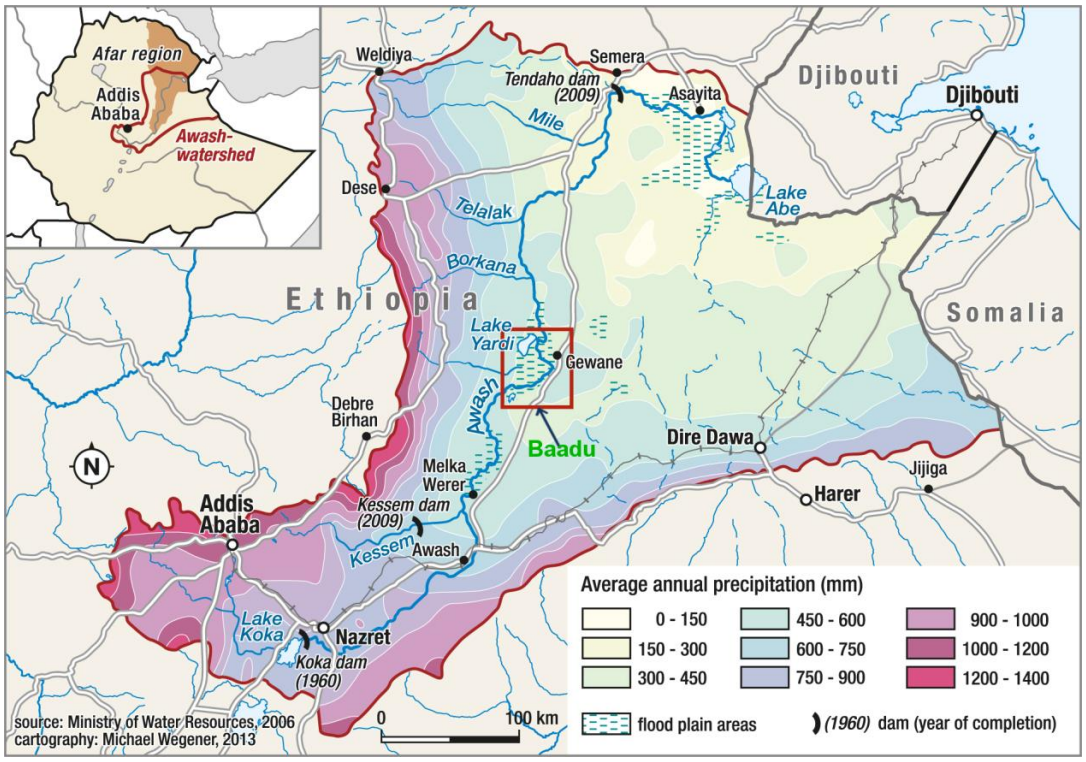

Figure 1: Location of Baadu case study site (Taken from AYANU et al., 2014)

Based on its range from the highlands to the Rift Valley, Awash Basin is subdivided into four zones: 1) The Upper Basin in the uplands extending from the river source to the Koka Dam; 2) Upper Valley, the rift floor between Koka dam and Awash close to Metahara; 3) Middle Valley extending from Metahara to Mile; and 4) The Lower Plains, the areas between Tendaho and Lake Abhe where the river terminates. The ridges around Addis Ababa that form the water division of the Blue Nile River are parts of the uplands of the basin. The middle Valley incorporates the irrigated areas from Metehara to Dubti with an elevation range of 500 to 1000 m a.s.l. The lower Valley forms the alluvial plains of Tendaho, Dubti and Asaiyta (Ayenew & Legesse, 2007). The upper and middle zones of the Awash Basin are currently getting increased attention in governmental plans to expand irrigated agriculture, as they are part of the economic base of the country where irrigated small and large scale state and private farms are located. Moreover, the middle Valley zone includes several national parks (Awash, Yangudi Rasa). These characteristics make the basin to have high consideration with respect to sustainable resource use and management.

Situated in the mid-Awash River Basin in the Afar Regional State of Ethiopia (Figure 1), Baadu has an approximate area of 1500 km2 and cmprises flat floodplains at an altitude of 500m above sea level surrounded by dry upland areas (Ayanu et al.). The Baadu floodplains were covered with abundant native grasses, an important fodder resource for cattle, while the surrounding hills were covered with different types of acacia trees (A. tortilis, A. senegal, A. mellifera) before *Prosopis juliflora* invasion. The area hosts more than twenty Afar clans who are mainly pastoralists (Rettberg, 2010).

Analysis of remote sensing data and quantifying temporal changes of *Prosopis juliflora* invasion

The mapping of *Prosopis juliflora* invasion was carried out using ASTER (15m resolution) satellite images taken during the dry season (October) of the year 2013. Dry season was preferably used since *Prosopis juliflora* remains green while other species shade leaves during this season which makes distinguishing it from other plant species easier. Prior to classification the images were corrected and training polygons were digitized from the ASTER images and cross-checked with high-resolution Google Earth images. The images were classified using supervised classification, maximum-likelihood method provided by Envi 5.0 software based on the training data. The classification results were validated using field data collected during dry period (February-March) 2014. Ground truth points were collected using Trimble Juno 3B GPS and overlaid with classification results to check the accuracy of the classification.

The temporal changes show the rate of expansion of *Prosopis juliflora* in the area and its extent of damage. We analyzed the temporal changes of *Prosopis juliflora* in Baadu based on our recent article, Ayanu et al. Our findings presented in Ayanu et al. are summarized and discussed in this report.

2.3 Results and discussion

Temporal changes of *Prosopis juliflora* invasion in Baadu

The temporal changes in *Prosopis juliflora* invasion in Baadu are presented in Table 1. *Prosopis juliflora* developed to an invasive stage gradually since its introduction to the wetlands of Baadu in the early 1980s. Results from remote sensing data analysis and field observations in our recent study (Ayanu et al.) showed that *Prosopis juliflora* was not invasive in the beginning years following its introduction around irrigated farms and permanent settlements (Figure 2). However, in the 1990s the species has already adapted to the host environment and become invasive especially in the abandoned state farms due to lack of instability that came up due to change of government in 1991. The agricultural activities on state farms located in the

Awash Basin were halted after downfall of the Derg regime giving more chance to *Prosopis juliflora* to aggressively invade the abandoned agricultural lands (Rettberg & Müller-Mahn, 2012). The variation in the extent (area) of invasion by *Prosopis juliflora* calculated from the maps of invaded areas demonstrated that this plant species is progressively advancing and is becoming the only dominant plant species in the region (See Table 1).

Year	Wetlands (Total Area 45000 ha)		Drylands (Total Area 207000 ha)		Irrigated Agriculture (Total Area 2000: 1187 ha; 2005: 2044 ha; 2010: 7205 ha; 2013: 6926 ha)	
	Area invaded (ha)	Proportion of invasion (%)	Area invaded (ha)	Proportion of invasion (%)	Area invaded (ha)	Proportion of invasion (%)
2000	3600	8	60	< 1	2	< 1
2005	8312	18	20	< 1	76	4
2010	13645	30	490	< 1	166	2
2013	20000	40	2500	<1	327	4

Table 1: Temporal changes in areas of land categories in Baadu invaded by *Prosopis juliflora* (taken from AYANU et al.)

The rate of *Prosopis juliflora* invasion over the past two decades is tremendously high (Figure 2, Table 1). Only from year 2000 to 2005 the total area of wetlands invaded by *Prosopis juliflora* increased from 3, 600 ha to 8, 000 ha increasing the proportion of wetlands invaded from 8 % to 18 % just over a period of five years. About 30 % of the wetlands was invaded in year 2010 amounting to total area over 13, 000 ha. This proportion further increased and until end of 2013 almost 40 % of the wetlands in Baadu was invaded i.e. 10 % increment over a period of 3 years when compared with year 2010.

The area of agricultural land invaded by *Prosopis juliflora* was only 2 ha (<1 %) in year 2000 even though it increased to 76 ha (4%) in year 2005. The invaded total area of agriculture increased to 166 ha in year 2010 but this amounts only to 2 % of the total agricultural land due to increased cultivated area compared with previous years. In the year 2013, some investors abandoned their farmland allowing *Prosopis juliflora* to continue invading the abandoned land and area of invasion increased to 327 ha though this is just 4 % of the total area of agricultural land in the same year. The increment in agricultural land area in the past decade is mainly due to increasing demand for cropland and government incentives and loans for those investing into agriculture. Frequent clearing and cultivation of agricultural lands is one of the main factors that slowed the *Prosopis juliflora* invasion (AYANU et al.).

Compared with moisture-rich flood plains of Baadu, the surrounding drylands were less invaded with a proportion less than 1 % of the total dryland area. As it was observed during the field visit, drylands with relatively less fertile and insufficient moisture content appear unfavorable for the growth of *Prosopis juliflora* (Ayanu et al.). The spreading pattern of *Prosopis juliflora* mainly follows the wetlands by excluding the drylands and forming an invasion-free corridor. For instance, the drylands between Baadu and Amibara serve as invasion-free corridors (Figure 3).

Further research questions regarding the spreading of *Prosopis juliflora*

To better understand the spreading patterns of *Prosopis juliflora*, identifying conditions that favor its spread is essential. The following points need to be considered for further research on *Prosopis juliflora* and its management.

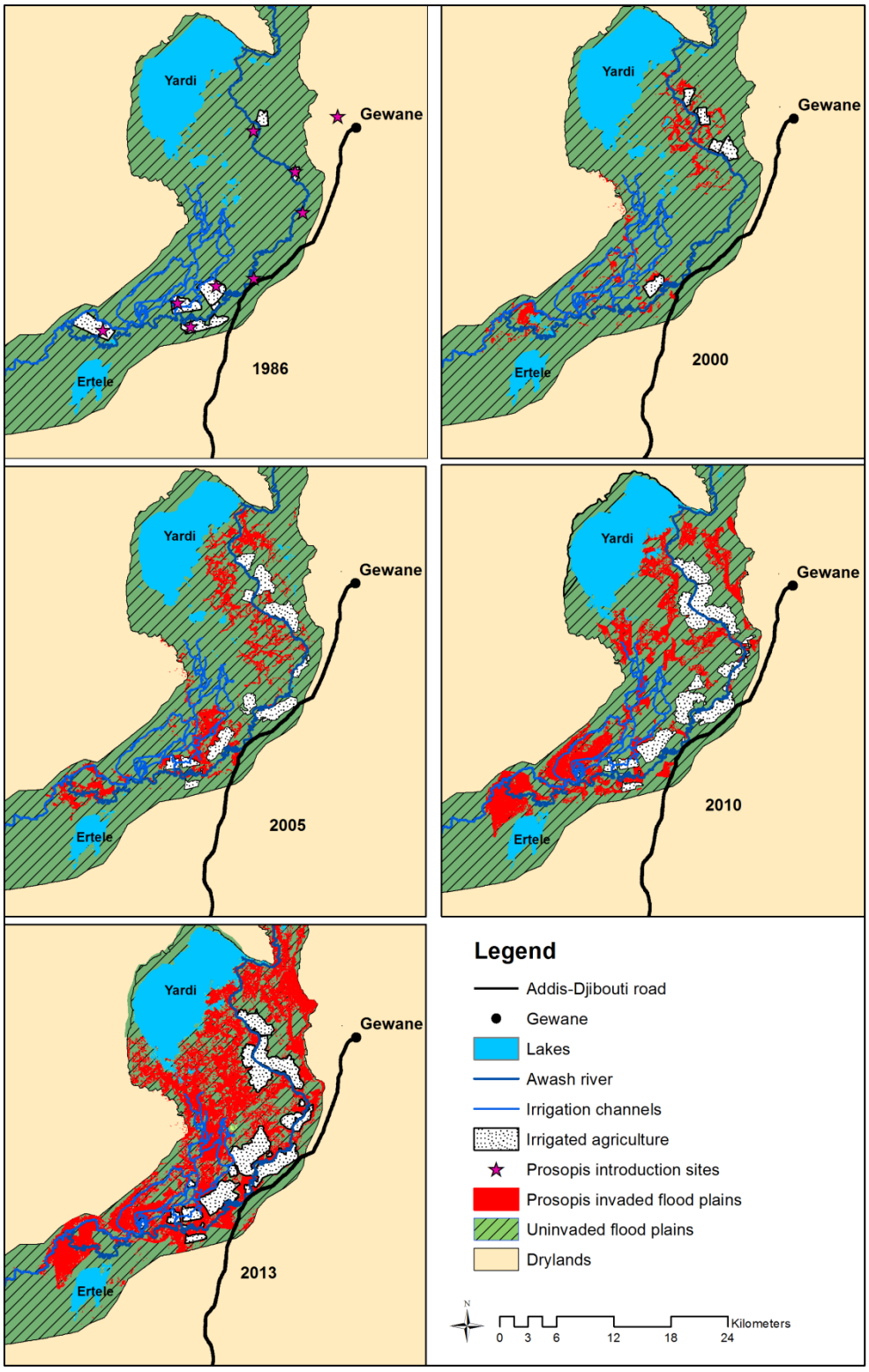

Figure 2: Temporal changes in *Prosopis juliflora* invasion of Baadu (Taken from AYANU et al.)

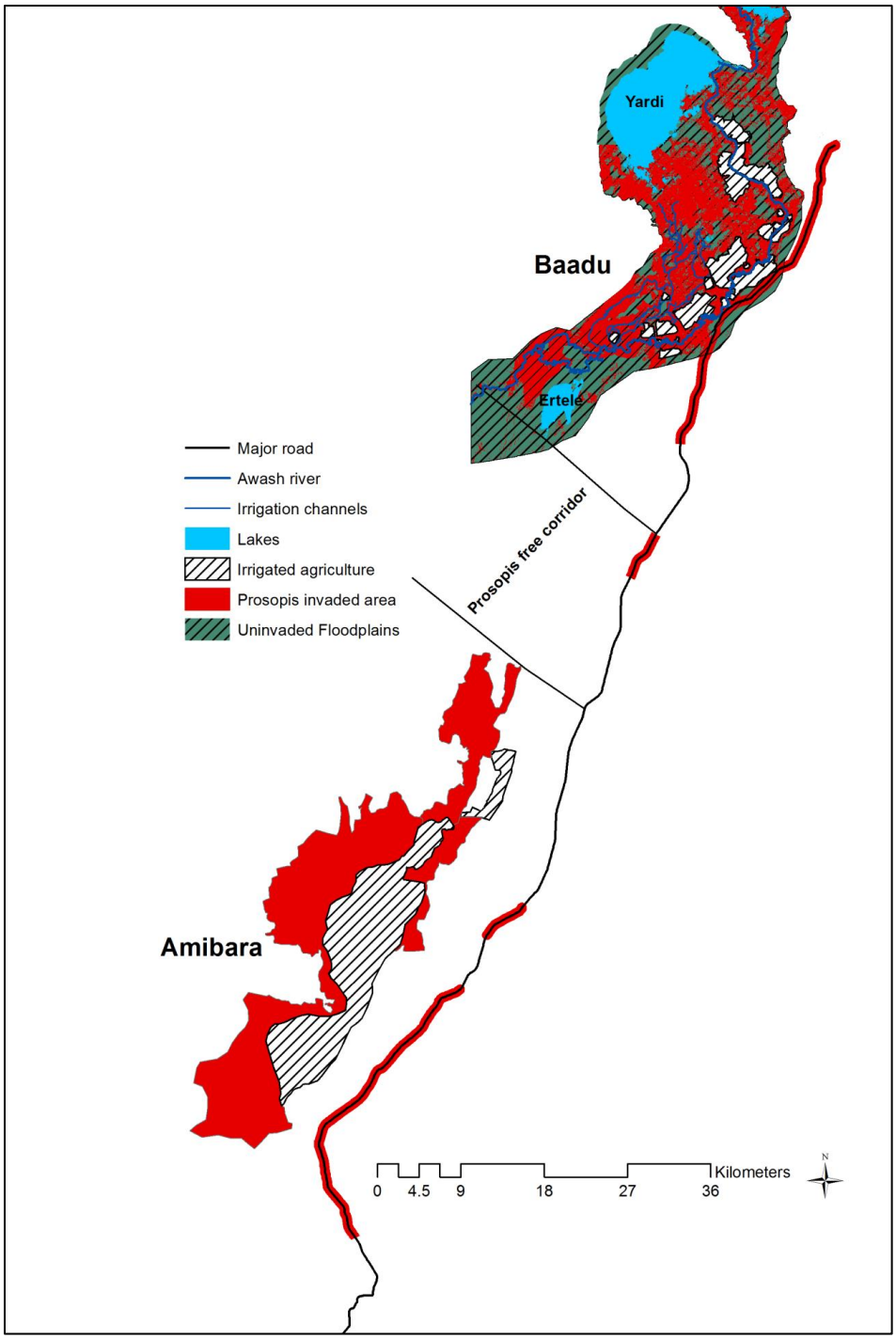

Figure 3: Discontinuity in spatial coverage of *Prosopis juliflora* invasion in Baadu and part of Amibara in October 2013. The flood plains of Baadu and Amibara are highly invaded while a dryland with about 20 km lies between the two flood plains causing discontinuity in *Prosopis juliflora* invasion.

Road-sides, favorable for *Prosopis juliflora* growth?

Prosopis juliflora invasion along roads has become a common phenomenon in the Awash Basin. Road-side areas appear to be points of *Prosopis juliflora* establishment prior to spreading into new uninvaded areas (Figure 4).

Dense shrubs of *Prosopis juliflora* were observed along the major road in Baadu and in Amibara. However, between Amibara and Baadu, there is a *Prosopis juliflora* free corridor which could be mainly due to the dry

nature of the land, hindering the spread of the species (Figure 4). The other reason for the reduced invasion of *Prosopis juliflora* in this area is the fact that it is a buffer zone for Afar and Isa clans. Since both clans rarely come to this part of the region to avoid conflicts, there are fewer animals that disperse *Prosopis juliflora* seeds. The species has spread following the major road from Djibouti to Addis Ababa. During field observation in February-March 2014 *Prosopis juliflora* were found spreading along the road and single shrubs were even observed after town Adama on the way to Addis Ababa. This is an indication that the species could spread from lower to high altitude areas.

Figure 4: Road-side dense *Prosopis juliflora* shrubs (AYANU, 2014)

Drylands: barriers for spreading of *Prosopis juliflora*?

As it was observed in the field *Prosopis juliflora* grows in areas where water is available i.e. floodplains. Thus, availability of water appears to be a limiting factor for the spread of *Prosopis juliflora*. Figure 5 shows the difference between floodplains and dry upland areas in terms of *Prosopis juliflora* invasion forming a distinct boundary that hinders spreading of the plant species.

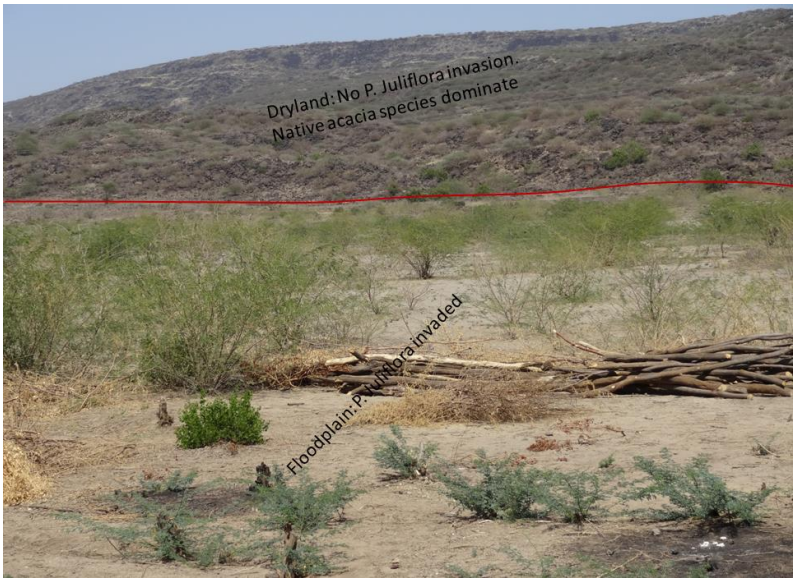

Figure 5: Difference in Upland and lower floodplain in *Prosopis juliflora* invasion (AYANU, 2014)

Settlement areas serve as points of start for *Prosopis juliflora* invasion?

Prosopis juliflora invasion is highly aggressive in settlement areas (Figure 6). The towns in Afar (e.g. Awash Arba, Gelealo, Meteka, Gewane) are invaded by *Prosopis juliflora*. It appears that animals feeding on pods of *Prosopis juliflora* disperse seeds in settlement areas enabling the species to be well established in the settlement areas.

After the *Prosopis juliflora* trees are matured and producing seeds, the spreading of *Prosopis juliflora* to new uninvaded areas could be facilitated through dispersal by animals. Thus, settlement areas have tendency to serve as points of start for *Prosopis juliflora* invasion.

Figure 6: *Prosopis juliflora* invasion in settlement areas (AYANU, 2014)

Irrigated agriculture creates favorable conditions for *Prosopis juliflora* invasion?

Irrigated agriculture involves cultivation and water supply to the soil which creates favorable conditions for *Prosopis juliflora* to take over the land after agricultural land is abandoned. Figure 7 shows newly upcoming seedlings of *Prosopis juliflora* in an agricultural land that was left uncultivated for several months.

Figure 7: Young *Prosopis juliflora* seedlings inside an agricultural land left uncultivated for a season (AYANU, 2014)

Irrigated agricultural land can remain useful only if there is continuous cultivation. Otherwise, *Prosopis juliflora* aggressively invades the land and converts it to dense shrubland within a short period of time. This has been the case with previous state farms in Baadu as well as recently abandoned private investment lands.

Dilemma: Should *Prosopis juliflora* be eradicated?

There is dilemma on whether *Prosopis juliflora* should be eradicated or not. The species has become the only dominant in the area and also has become an economic source for the people in the area for instance, charcoal production. In Baadu and the surrounding areas charcoal production has recently become the

main source of income for people that are involved. There are various groups that are involved in charcoal production chain (Figure 8).

Though *Prosopis juliflora* invasion has been causing severe problems on the livelihood of the local people, there still remain people who benefit from exploitation of the plant species for charcoal production. Coppicing and regeneration capacity of *Prosopis juliflora* makes the plant species continuing source of wood for charcoal production in the region. Thus, attempts in eradication of the species need to take into account this crucial issue.

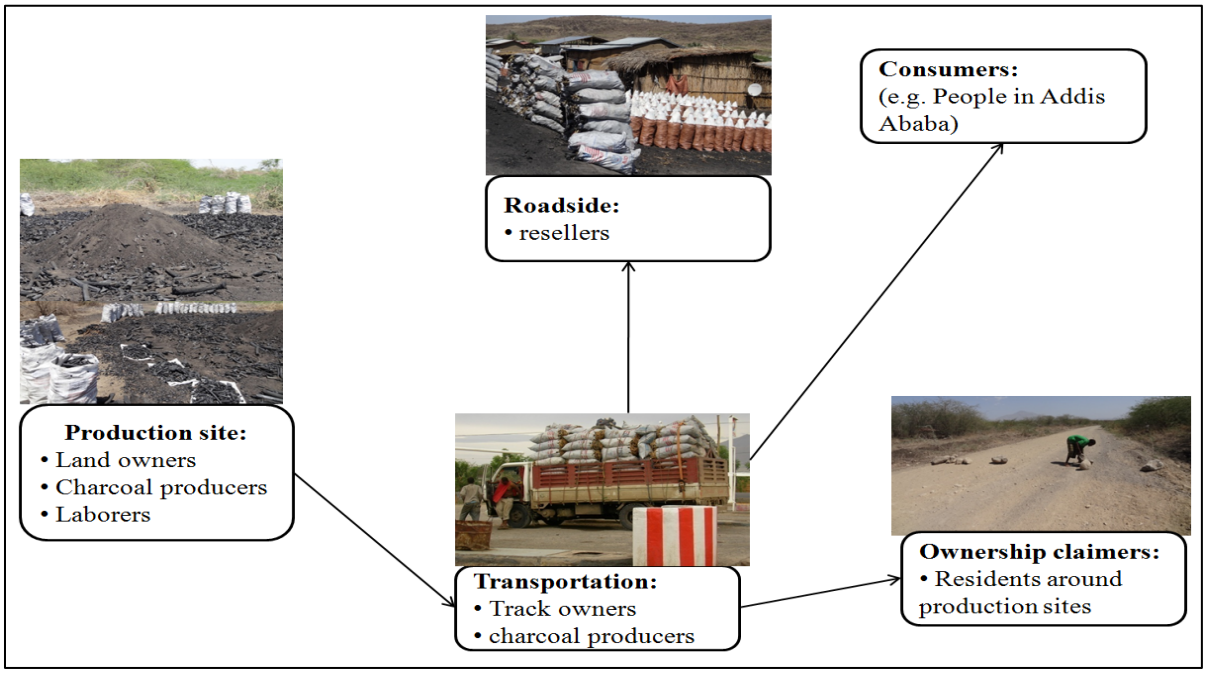

Figure 8: Charcoal production chain and beneficiaries at different stages (AYANU, 2014)

2.4 Conclusions and outlook

In a nutshell, over the past two decades *Prosopis juliflora* continuously spread to new areas especially in the flood plains of Baadu. Thus, more efforts are needed in order to control its invasion and ensure sustainable resource use and management in the Awash River Basin in particular and the rest of Ethiopia in general.

The seed dispersal mechanisms, soil preference, and water demand of the species needs to be further investigated. More emphasis needs to be given to finding effective management practices to control the damage caused by *Prosopis juliflora* invasion. Due to their high susceptibility, flood plains in the Awash Basin should be continuously monitored with regard to invasion by *Prosopis juliflora*. Management of *Prosopis juliflora* requires an integrated approach where experts from various disciplines are involved. Different stakeholders such as the pastoralists, agro-pastoralists, large-scale investors on agriculture, government organizations and NGOs should work together to find an optimum solution to halt its drastic effect.

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3. Ecological challenges and potential carbon storage benefits of *Prosopis juliflora* in Afar

Anna C. Treydte, University of Hohenheim, Germany
Emiru Birhane, Mekelle University, Ethiopia
Abeje Eshete, Forestry Institute, EIAR, Ethiopia

3.1 Introduction and state of the art

Invasive alien species are a global phenomenon and often have detrimental effects on the fauna and flora biodiversity. In Ethiopia, *Prosopis juliflora* invasion has been devastating; rangeland areas have been degraded and forage grass productivity has declined drastically as a result (WAKIE et al. 2012, ANGASSA & OBA 2008). Soil erosion and a loss in livestock productivity have been the consequences, leading to fewer and lower quality rangeland sites available to pastoralists (GERBER, 2012). The spatial extension of *Prosopis juliflora* in Ethiopia is difficult to assess since it is expanding rapidly, up to 18% per year (FELKER, 2008). One mill ha is already covered by *Prosopis juliflora* in entire Ethiopia (RYAN, 2011), of which about 700,000 ha are located in the Afar Region (MUELLER-MAHN et al., 2010). A further rapid spread is to be expected (Figure 1).

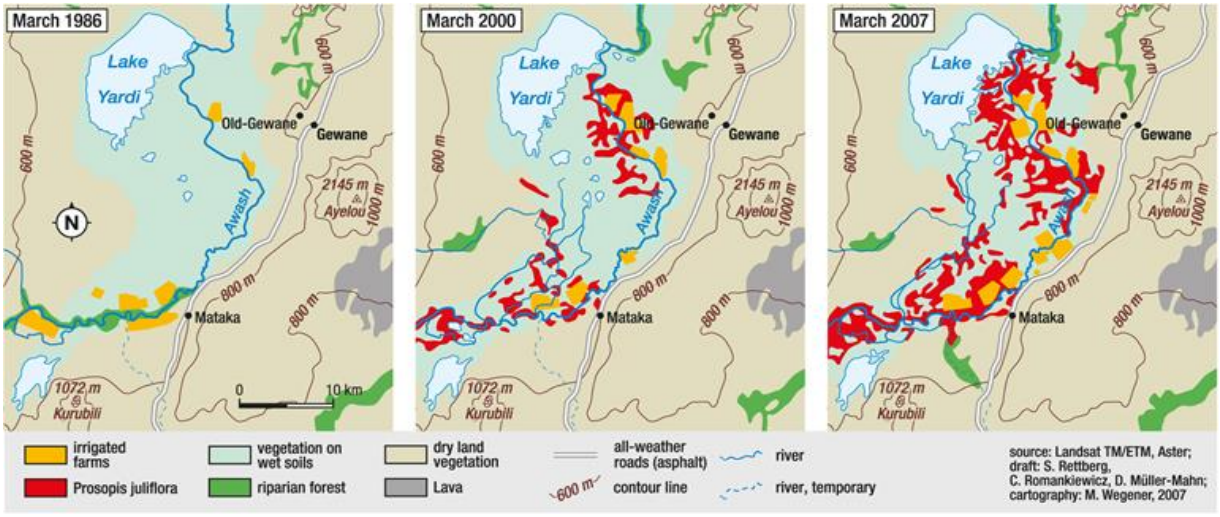

Figure 1: Expansion of *Prosopis juliflora* within Baadu Area, Afar, from 1986 – 2007 (RETTBERG & MUELLER-MAHN, 2012)

Attempts of controlling and managing *Prosopis juliflora* in the Afar Region have often lacked an overall long-term ecological perspective on consecutive shifts in ecosystem functioning. *Prosopis juliflora* outcompetes important forage species and, thus, reduces long-term forage availability and, hence, the sustainability and quality of livestock production. The remaining low quality rangelands might force pastoralists into shifting their livestock practices drastically or even adopting other income generating activities. Hence, the vulnerability of pastoralists has increased and drought-induced acute food insecurity has been replaced by chronic food insecurity for large parts of the pastoral population (Mueller-Mahn et al., 2010).

Estimating aboveground plant biomass with sufficient accuracy can help estimate forage biomass available and establish the C stored in forests, which form a major component of the C reserves in the world's ecosystems (Houghton, 2007). Woody plant encroachers in savanna systems (Munyati et al., 2010) are of concern to pastoralists as they reduce stock carrying capacity (Angassa & Oba 2008). Higher tree densities will, on the other hand, significantly increase the carbon (C) storage capacity of the grassland systems (Hughes et al., 2006). To quantify the net gain in C stocks due to woody plant proliferation in grassland ecosystems reliable estimates of the standing biomass are required. The invasive properties of *Prosopis juliflora* might increase the overall C storage potential of the ecosystem.

To alleviate stress symptoms plants grow in association with a number of soil microorganisms (Marulanda et al., 2003) such as the common Arbuscular Mycorrhizal (AM) fungi (Kleikamp, 2002). The development of AM fungi varies with host species, plant life history stage, resource availability and abiotic conditions, soil type, depth and season (Gai et al., 2006). The distribution and density of mycorrhizal fungi are highly influenced by the type of vegetation and land use types. This study was carried out to study AM fungi status of *Prosopis juliflora* trees grown at different invasion rates.

The soil seed bank addresses rangeland resilience and recovery processes with respect to native woody and herbaceous species that can regrow once an area has been cleared from *Prosopis juliflora*. Little soil seed bank research has been undertaken in Northern Ethiopia, mainly in exclosures and church forests. This research aimed at assessing the soil seed bank potential as a means for rehabilitation of the invaded grazing land after removal of *Prosopis juliflora*.

Our study investigated *Prosopis juliflora* infestation along an encroachment gradient and in restored sites (eradication of *Prosopis juliflora* about six months prior to this study) and we aimed at:

- Quantifying the woody species abundance, diversity and biomass
- Quantifying the potential above- and below-ground Carbon stocks
- Investigating soil properties (water holding capacity, nutrients)
- Addressing soil microbial communities
- Assessing the recruitment potential of *Prosopis juliflora* (seedling numbers)
- Recording the seed bank potential of herbaceous and woody vegetation.

3.2 Material and Methods

Study area

We selected Amibara and Gewane Woredas (Zone 3), close to the Werer Research Center (Amibara (UTM: 0631147, 1029406) and Gewane (UTM: 0668034, 1126548)) of different invasion rates including sites with no *Prosopis juliflora* incidence and restoration sties. Average annual rainfall was 697 mm and average annual temperature ranged from 21 to 38 °C. The study sites were along the main road from Addis Ababa to Djibouti. The dominating woody plant species were Acacia senegal and *Prosopis juliflora*. Most of the land had been used for pastoralism while only little of the area has been used for agriculture.

Experimental design and layout

We included six categories of *Prosopis juliflora* infestation: "None" (no *Prosopis juliflora* individual present), "low" (low infestation), "medium" (intermediate infestation), "high" (high infestation), "canal" (high infestation along irrigation canals) and "restored" (area restored by the Werer Melka institute and local communities about 6 months prior to our study; Fig. 2). The immediate surroundings of irrigation canals were as densely infested as areas next to the main asphalt road. The invasion rate of *Prosopis juliflora* decreased with distance away from the road as was assessed during preliminary analyses. We employed a systematic random sampling technique: eight transects of 1000 m length were laid out perpendicular to the road. The distance between each parallel line transect was 1.5 km. Each transect, hence, intersected the high, medium, low and none categories of *Prosopis juliflora* cover with increasing distance away from the road. Within each encroachment category we located 12 plots, 200 m apart from each other. Plots at the no *Prosopis juliflora*, low, medium and restored categories were 20m x 20m while plots at the high infestation category were 5m x 5m due to logistical reasons. The total number of plots was 50.

Vegetation sampling

All tree and shrub species ≥ 1.5 m height within each plot were identified with help from the National Herbarium, Addis Ababa University. All trees/shrubs ≥ 0.5 m and ≤ 1.5 m height were systematically measured (root collar diameter, crown width and height). Thirty eight individuals of the two most dominant woody species, *Prosopis juliflora* and A. senegal were sampled for allometric equations. For biomass measurements a fresh biomass subsample of 250-500 g for each stem, gross branch and thin branch component was brought to the laboratory for dry biomass determination, dried to constant mass for 72 h at 105 °C (KETTERINGS et al., 2001) and then weighted.

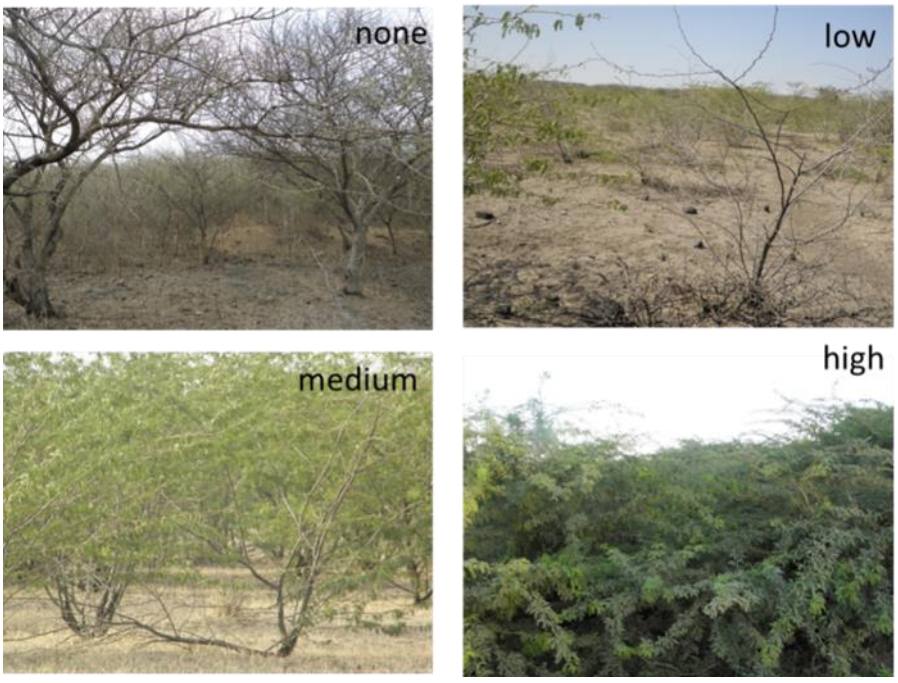

Figure 2: Four encroachment categories of *Prosopis juliflora* at our study sites.

Soil Sampling

Soil samples for soil bulk density and organic matter as well as nutrient determination were collected from the surface soil in quadrants using core sampler carefully driven into the soil to avoid compaction (ROSHETKO et al., 2002).

Further, from the rhizosphere of selected trees, soil and root samples were collected for spore analysis, assessment of AM fungal colonization, soil physical and chemical analysis. Composite soil samples were collected from two soil depths (0-15 cm and 15-30 cm) and four directions around the *Prosopis juliflora* tree. A sub-sample of approximately 100 g was taken for the extraction of AM fungal spores. The soil samples were air dried, passed through a 2 mm sieve and stored at 4 ^{0}C before analysis. For bulk density measurement undisturbed soil samples were collected from the same area.

3.3 Results

Woody species composition

		Invasion rate			
Site	**Species**	**High**	**Medium**	**Low**	**None**
Amibara	*Acacia melifera*	0	9	25	0
	Acacia senegal	0	0	0	928
	Dobera glabra	50	22	3	0
	Prosopis juliflora	4200	503	325	44
	Total	4250	534	353	972
Gewane	*Acacia melifera*	0	0	0	13
	Acacia senegal	0	0	0	863
	Acacia seyal	0	0	25	0
	Acacia spp.	0	0	50	0
	Acacia tortilis	0	0	0	13
	Balanaytes aegyptica	0	0	13	0
	Dobera glabra	0	0	0	12
	Prosopis juliflora	3850	1775	1513	13
	Total	3850	1775	1600	913

Table 1: Number of individuals per species for all woody plants recorded in the sample quadrats across the different *Prosopis juliflora* encroachment sites.

In our study sites, *Prosopis juliflora* dominated most infestation categories while Acacia senegal dominated in areas that were not infested by *Prosopis juliflora* (Table 1). In general, we found rather low species diversity and richness of the woody vegetation in Gewane and Amibara, with about 4-5 species per encroachment site. Population structure of *Prosopis juliflora* showed relatively large numbers of individuals in the second diameter class (2–4 cm) in the high, medium and low invasion category. The number of individuals decreased with an increase in diameter size suggesting high utilization intensity in the larger diameter class

(Figure 3). Higher number of seedlings (<2 cm) was observed in the medium and low invasion areas. The low number of seedlings in the high invasion rate indicates the low regeneration potential of *Prosopis juliflora*, likely due to high competition and alleopatic effects.

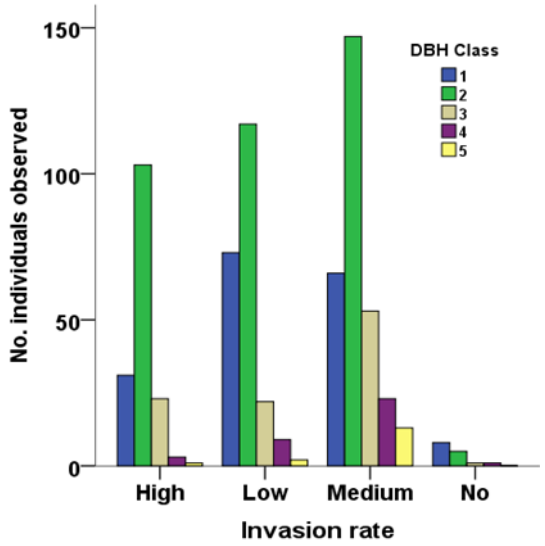

Figure 3: Number of *Prosopis juliflora* individuals of different diameter classes. 1 = <2 cm, 2 = 2-4 cm, 3 = 4-6 cm, 4 = 6-8 cm, 5 = >8 cm across the four different encroachment categories.

Carbon stocks and plant biomass

Prosopis juliflora biomass weight was easily predicted using allometric measurements such as root collar, crown diameter, tree height (Figure 4).

Figure 4: Field work assessment of specific tree structure parameters and biomass estimates based on destructive harvesting.

Tree structure measurements of *Prosopis juliflora* and A. senegal, the two most dominant woody plant species, could be used to predict overall biomass reliably (R^2 = 74.4 - 99.1%). Hence, if we are interested in knowing how much biomass is available as forage / for firewood production / as C storage potential, some simple tree measurements are sufficient. Overall woody vegetation biomass declined with decreasing invasion rate. Low infested sites and areas close to irrigation water ways (canals) showed half the biomass than highly infested sites (Table 2). This trend was similar for above and below ground biomass. Rehabilitated sites showed biomass as low as areas without any infestation. Basal cover of native herbaceous vegetation was further strongly reduced under high *Prosopis juliflora* infestation.

Invasion rate	High	Medium	Low	None	Rehabilitated	Canals
Above ground biomass (t/ha)	61	42	28	12	13	30
Below ground biomass (t/ha)	16	11	7	3	3	8
Total biomass	77	53	35	15	16	38

Table 2: Above and below ground biomass of *Prosopis juliflora* across the different infestation categories as quantified through destructive harvesting.

Soil properties

Soil available Phosphorus and soil organic Carbon were more than twice as high at highly and intermediate infested sites compared to low and not infested sites (Figure 5). A similar variation was observed for TN. There was significantly higher N in the high and medium invasion rates compared to the low and no invasion category. The site of low *Prosopis juliflora* infestation showed the lowest organic Carbon contents in the soil.

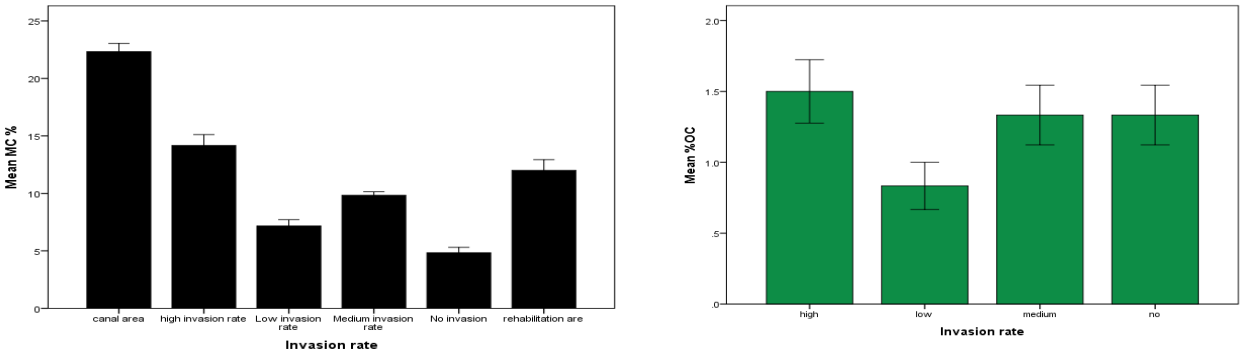

Figure 5: Available a) phosphorus and b) organic carbon content (±SE) of soil in differently encroached areas.

Hence, soils in densely and intermediate *Prosopis juliflora* encroached sites show good quality for current and future plant growth. The woody plant encroacher might have contributed to these positive soil properties through litter fall, changing of micro-climate, nitrogen-fixation potential and the extensive, particularly deep-reaching rhizosphere. Moisture content in soils of canal areas and highly infested areas was more than twice as high than that of low or no infested areas (Figure 6). Medium infested sites and rehabilitation sites showed a moisture content in between of about 11-13% in the soils. Hence, *Prosopis juliflora* seemed to be efficient in accumulating moisture at the surface soils in their immediate surroundings, which might be due to its long tap roots reaching the soil water table and the dense canopy cover protecting soils from too much sunlight and changing the microclimate to cooler temperatures and, hence, less evapotranspiration. The soil microorganism community was analysed by investigating spore abundance of various soil microbiota (Table 3).

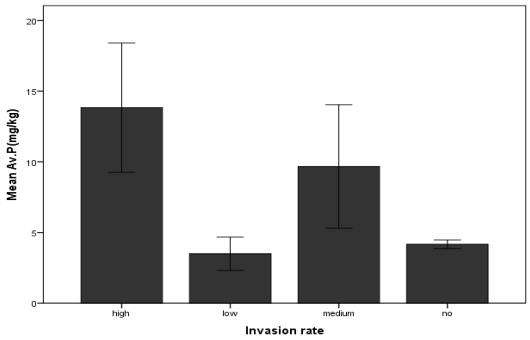

Figure 6: Average moisture content (±SE) of soil under various *Prosopis juliflora* infestation categories

Invasion rate	**Spore abundance**	
	0-15 cm depth	15-30 cm depth
High	223.7 ± 64.5	92.2 ± 26.6
Medium	138.8 ± 37.1	136.7 ± 36.5
Low	193.8 ± 47.1	88.9 ± 21.5
None	192.8 ± 55.6	67.2 ± 19.4

Table 3: Average spore abundance of microbiota in soils of different depth. Four *Prosopis juliflora* infestation rates were analysed.

Spore abundance was twice as high in upper soil layers as in lower soil layers. The lowest spore abundance was found in medium dense *Prosopis juliflora* invasion sites; at medium infested sites the spore numbers were similar in deep and shallow soils while in general the deeper soil spore numbers were more than half that of the top soil layer. Four spore genera were recorded in all land use types. Glomus was the most abundant and most frequently found genus in all invasion rates followed by Gigaspora, Scutellospora and Acaulospora. AM root colonization varied from 61.5% to 71.1% for *Prosopis juliflora* trees grown at different invasion rates, highest at highly invaded sites and lowest at no invaded sites (P = 0.009). The majority of the species showed AM structures in their roots (Arbuscule, Vesicle or Hyphal coils).

Soil seed bank

Most of the recovered species from the soil seed bank were grasses and herbs. So far only two *Prosopis juliflora* seedlings have germinated from the low and medium invaded soil seed banks. However, the soil seed bank is only 41 days old, i.e., there might still be seeds emerging in the later stages of this experiment (Table 4). Almost twice as many seedlings resprouted from the high and intermediate infested sites compared to the sites with low or no *Prosopis juliflora* present. Our current results suggest that *Prosopis juliflora* might have allelopathic effects onto its own seedlings by suppressing their resprouting abilities in the close neighbourhood of the parental tree. Further, only few native tree seedlings started sprouting, indicating that the herbaceous layer species might still be present even after long-term *Prosopis juliflora* invasion.

Invasion rate	No. of seedlings
high	18
medium	18
low	9
none	10

Table 4: Number of seedlings resprouting in soil of different *Prosopis juliflora* infestation. Seed bank was 41 days old at this time.

3.4 Conclusion

Our results showed that the highly and medium infested sites encompassed beneficial soil properties for plant growth (high moisture, N, P contents, high soil OM and water content). Despite desirable soil properties, the herbaceous layer beneath highly and intermediate encroached sites cannot represent a suitable forage resource for livestock in *Prosopis juliflora*-dominated Amibara and Gewane. Management will require physical removal and cutting of *Prosopis juliflora* but will probably not require reseeding of native plants. As the seed bank in Amibara and Gewane still seems intact there is potential to reclaim land covered by *Prosopis juliflora*, even if the encroachment phase has been going on for several decades. It will probably be of advantage to leave some *Prosopis juliflora* plants and let them grow into tall trees within the rangeland to use their beneficial effects onto the environment of their immediate surroundings. As we saw in our restored land, after 6 months first resprouting of *Prosopis juliflora* occurred. However, our study suggests that *Prosopis juliflora* does not establish at sites where native woody vegetation species are already present. It rather infests areas that have been overgrazed and lack both a healthy woody and herbaceous layer component. Thus, preventing the fresh growth of *Prosopis juliflora* in vulnerable sites (e.g. sites of low or no infestation) is crucial. Sites of high encroachment did not show a high proportion of *Prosopis juliflora* seedlings, i.e., we expect that *Prosopis juliflora* will become less abundant over time due to self-thinning and its allelopathic effects. *Prosopis juliflora* invasion success seemed to be supported by the presence of species-specific mycorrhizae. The high number of spores at highly invaded areas could be due to a low level of soil disturbance/ tillage, high number of plants with interconnected roots, high vegetation cover and more active biological conditions compared to plots in open areas. Generally, to ensure efficient plant growth and to rehabilitate the indigenous grass after removal of *Prosopis juliflora* it has been suggested to enhance the native soil mycorrhizal potential, especially under semiarid regions which are often characterized by low levels of P availability in soil (NDOYE et al., 2012). The enhanced biomass and Carbon stocks through *Prosopis juliflora* encroachment might be positive for climate change mitigation activities. Carbon stocks through enhanced biomass above and below ground as well as higher organic matter content in soils can contribute to capturing CO_2 from the atmosphere (YUSUF et al. in review) and future Carbon trade efforts and might provide an alternative income generation through payment for environmental services (PES).

Overall, our study suggests that it is not too late for rehabilitation of *Prosopis juliflora* infested sites. These sites still contain a high regeneration potential of native species as shown in the soil seed bank. Current management, however, might not be sufficient and often rather encouraging additional *Prosopis juliflora* growth after coppicing. Aiming management at seedling spread prevention as well as slight but long-lasting thinning (but not eliminating) activities are the way forward.

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3.6 Further Information

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4. A social-economic assessment of the impact of *Prosopis juliflora* invasion and participative management approaches in the Afar Region, Ethiopia

John Ilukor, University of Hohenheim, Germany
Regina Birner, University of Hohenheim, Germany
Mesfin Tilahun, Mekelle University, Ethiopia
Shimelis Getu, Samara University, Ethiopia

4.1 Introduction

The Woody shrub or plant *Prosopis juliflora*, native to Mexico, South America and the Caribbean has become a devastating invasive shrub in the Afar Region in Ethiopia. Growing to a height of 12 meters and with trunk diameter of 1.2 meters, *Prosopis juliflora* forms impenetrable spiny thickets along riverbanks and floodplains, reducing biodiversity and pasture production, by denying native plants water and sunlight, and not providing food for native animals and cattle. The plant was first introduced to Afar Region in the late 1970s and early 1980s to combat desertification. Non-governmental organization especially FARM-Africa and Care Ethiopia are looking for ways to commercialize the woody tree. Existing literature on *Prosopis juliflora* also show that the shrub offers significant opportunities for rural households such as income and livelihoods diversification as well as ecological benefits like microclimate regulation, improvement of the soil fertility and desalinization of the soils (BERHANU & TESFAYE, 2006). KAHI & NGUGI, (2009) found that soils under the *Prosopis juliflora* had higher organic carbon and total nitrogen than the soils in the open areas. Even though the soils under the acacia trees had higher organic carbon and total nitrogen than soils under *Prosopis juliflora*, the acacia trees are not capable of sustainably surviving in Afar Region and continue to provide fuel wood, charcoal and regulate the micro climate compared to *Prosopis juliflora*. *Prosopis juliflora* high coppicing ability and the deep roots enable it to survive in desert areas and provide a number of benefits including alternative energy sources. The pods from *Prosopis juliflora* can also be a source of nutritious human food (CHOGE et al., 2007), and can be a source of nutritious, less costly feed ingredient for livestock (CHATURVEDI & SAHOO 2013, SAWAL et al. 2004, STEIN & TOLEDO, 2005). In Afar a region, *Prosopis juliflora* is also attributed to have increased crop yields by 29% (HAJI & MOHAMMED, 2013).

Nonetheless pastoralists who call it the "Devil Tree" and the “AIDS” to the animals insist that *Prosopis juliflora* should be eradicated. Effective control of *Prosopis juliflora* has been difficult because of the extent of infestations, the aggressive nature of the shrub and the type of terrain where it occurs. Worse still, policy makers and development partners are faced with the dilemma of whether to manage *Prosopis juliflora* invasion or to completely eradicate it. If they have to eradicate *Prosopis juliflora*, who are the beneficiaries, the losers and what are cost effective methods of controlling or eradicating *Prosopis juliflora*? This study attempts to answer these questions by quantifying the total economic value of *Prosopis juliflora* invasion and examining the cost effectiveness of different *Prosopis juliflora* participative management and control

approaches. The study was done in Awash, Gewane and Amibara Woreda along the Awash River in Afar Region, north-eastern Ethiopia. The Afar Region covers an area of 108,860 km², hosting a population of approximately 1.4 million people with around 87% living in rural areas, mostly depending on livestock production for multiple purposes such as food consumption, income-generation, transport and asset reserves.

4.2 The total economic valuation

The total value of *Prosopis juliflora* invasion evaluated based on the concept of the Total Economic Value (TEV). The notion of total economic value (TEV) provides an all-encompassing measure of the economic value of any environmental asset including use and non-use (or passive use) values. Direct benefits generated from *Prosopis juliflora* invasion in Afar Region are increased supply of good quality wood which is used for as fire wood, fencing, wind braking, can be sold and used for charcoal burning to be sold to generate income (BERHANU & TESFAYE 2006, ODUOR & GITHIOMI 2013). Both crushed and uncrushed *Prosopis juliflora* pods can be fed to animals (BERHANU & TESFAYE, 2006). Moreover, these pods can be used for human consumption and have been found to be rich in proteins, carbohydrates, fibre, calcium, phosphorus and essential amino acids (FELKER et al. 2001, PASIECZNIK et al. 2013). Feeding animals with *Prosopis juliflora* pods would lead to death in animals by inducing a permanent impairment of the ability to digest cellulose (DUKE 1983, LEWIS & ELVIN-LEWIS 2004) and is associated to increase in malaria cases in the invaded areas (BERHANU & TESFAYE 2006, MWANGI & SWALLOW 2008).

Prosopis juliflora invasion has also been linked increased crop yields per hectare because it has the ability to improve soils by fixing nitrogen, mulching the soil with its leaves and desalinizing the soils (FELKER et al. 2001, KAHI & NGUGI 2009). The flowers of *Prosopis juliflora* produce pollen grains and nectar that have high in sugars which are forage for bees thus supporting production of honey (FELKER et al. 2001, VARSHNEY 1996). Honey and it's by products can be sold to generate household income. Burkart (in FELKER et al., 2001) estimates that bees may extract enough nectar and pollen from a single flowering tree which is equivalent to one kilogram of honey and 100-400Kg/ha/yr. *Prosopis juliflora* is also an ecological resource as it provides important habitants for plant and animal species, helps in combating drought and desertification (VARSHNEY, 1996). The *Prosopis juliflora* trees have also provided protection as well as food for wild animals and ameliorated environmental conditions through carbon sequestration (FELKER et al. 2001, KAUR et al. 2012). FELKER et al., (1990) estimated that *Prosopis juliflora* can sequester carbon biomass extending from 0.65 kg to 1300Kg per kg/stem which is equivalent to 2-20 tonnes per hectare. *Prosopis juliflora* extracts can be used against diarrhoea, stomach disorders, eye infections, (FELKER et al. 2001, ROCHA 1988), and treatment of sexually transmitted disease like Gonorrhoea (CÁCERES et al., 1995). It also has a potential of being used as potential bio-control agent for invasive weed species, pest and virus (DHAWAN 1995; KANNAN & DORAISWAMY,1993). *Prosopis juliflora* also have indirect negative benefits that emanate from its ability to colonize rangelands, farming areas, access to water ways and reduce plant species in the plots it invades. In India, species richness is estimated to reduce by 63% under *Prosopis juliflora* compared to open land (KAUR et al., 2012). KAHI & NGUGI (2009) also found that cover of understorey herbaceous plant species in plots invaded by *Prosopis juliflora* were 27% less than that in the open areas. By reducing the plant species, *Prosopis juliflora* inflicts significant production losses to livestock and pastoralists inform reduced milk production, reduced body weight.

However some of these non-use values such as microclimate regulation, nutritional and medicinal impacts are very difficult measure. Nonetheless, economists have developed a number of techniques to measure these values such as stated preference techniques particularly contingent evaluation technique used to estimate or elicit both use values and non-use values based on questionnaires and revealed preference

techniques (market price-WTP) which work by pursuing markets in which the value of the good or service in question might be revealed (OECD, 2006). Also, "dose-response functions" that link one variable with another can be used (OECD, 2006). For example, to link increase in malaria cases *Prosopis juliflora*, we exploited the relationship between increased malaria cases and changes Normalized Difference vegetation Index (NDVI) based on study of *Prosopis juliflora* invaded area in India by Baeza et al., 2011. All these three methods were used to try to impute the values of *Prosopis juliflora* invasion in Afar. In addition, cost effectiveness of different control or management strategies was examined. The net benefit were also calculated for each scenario by comparing the TEV with and without control ($TEV_c - TEV_i$), adding the benefit from reduced social losses ($C_i - C_c$), and subtracting the costs of control. Since the time dimension was to be taken into account, the calculation was based on the principles of investment analysis. Hence, future cost and benefit streams were discounted to calculate the Net Present Value of *Prosopis juliflora* invasion and control.

The data used in this study was collected using both qualitative and quantitative techniques. Qualitative techniques such as literature review, focus group discussions, interviews with local experts, farm Africa staff, and researchers, as well as observation techniques were used to collect primary data. The interviews and the meetings were held in Awash, Gewane and Amibara which were the selected study districts (Woreda). Structured questionnaire were used to collected data at a household level from 18 villages (Kebeles). Amibara had the highest number of Kebeles, followed by Gewane and Awash respectively. The Kebeles were categorized as highly invaded, moderated invaded and less or no invasion. Proportionate simple random sampling technique was use to select the villages to selected in each Woreda. In Amibara, 8 Kebeles were randomly selected for the household survey, 6 from Gewane and 4 from Awash. Also, out of the 8 Kebeles selected in Amibara, 4 were highly invaded, and other 4 were less invaded. In Gewane, out of six Kebeles, 3 were selected from each category and in Awash; two was selected from each category. The total number of household interview were 490 including 213 from Amibara, 177 from Gewane and 100 from Awash Fenetal.

The sampling frame was generated with help of Kebele leaders. They were given exercise books and asked to register a list of all households in their Kebeles as well as the type of animal and number of animals owned. To ensure that all households of different poverty and income levels are included in survey, the sample was stratified in to rich, middle and poor class. Wealth ranking based on number and type of livestock owned and validated during the focused group discussion. According to community members a household with camels or one camel, shots and cattle is considered rich while households without camels but with shots and cattle are considered as middle class households. Poor households are those with only shots and one or two cattle are considered poor. Bids values for estimating willingness to pay (WTP) and contribute for *Prosopis juliflora* eradication and control were determined based on the wealth ranking. Insights from FGDs were integrated in to the questionnaires. The question on perception of households on *Prosopis juliflora* invasion and control methods, uses and impacts of *Prosopis juliflora* invasion were included in the questions. Special questionnaire was also developed and administered to cooperative leaders to ascertain the institutional issues affecting the cooperative activities. Secondary data on different control methods, *Prosopis juliflora* coverage, and its ecological and economic impacts were also collected from FARM Africa and Amibara research station.

4.3 Results

Social characteristics and perceptions about *Prosopis juliflora* invasion

The results from the socio economic survey reveal that about 65% of households are pastoralist and 23% are agro-pastoralists. Only 3% depend on crop farming as main source of livelihood while 6% and 3% are employed either as casual labourers and traders respectively. Over 91% of households stated that bush land (communal) land is highly invaded and 79% stated that pasture lands to be highly invaded by *Prosopis juliflora* because it had formed a dense canopy prohibiting their animals from grassing. Only 10% and 38% of the households stated that government and crop land respectively to be invaded by *Prosopis juliflora*. This means that crop and government lands are the least invaded mainly because these lands are continuously being used compared to the bush and grasslands. The survey also results indicate that most Afar households have limited knowledge of most local and industrial uses of *Prosopis juliflora*. In the case of local uses, about 34% knew all, 46% knew few and 20% did not know any local use of *Prosopis juliflora* while 82% did not know any of industrial uses of the *Prosopis juliflora*. However, 64% of the households stated they knew negative impacts of *Prosopis juliflora*, 28% knew few of them and only 8% knew none.

The study also examined household's perceptions on extent of concern about negative impacts of *Prosopis juliflora* and level of benefits. Only 5% of households believe that they fully benefit from *Prosopis juliflora* invasion, 15% think they partially benefit, 51% think they benefit little while 30% stated that they do not benefit from *Prosopis juliflora* invasion. A bout 95% of the households stated they are concerned with the negative impacts of *Prosopis juliflora* and only 5% of the household were not bothered by *Prosopis juliflora* invasions.This probably explains why 84% of the households had actually preferred complete eradication of the *Prosopis juliflora* and while only 16% were for management or control of the invasion. The results also reveal that it is mainly the pastoralists and agro-pastoralists who are interested in complete eradication of *Prosopis juliflora* because it greatly affects their livestock production. However, others who have another source of livelihood and generated some benefits from *Prosopis juliflora* prefer control rather than completed eradication.

Benefits from *Prosopis juliflora* invasion

- **Environmental income:** The main local use of *Prosopis juliflora* is for fuel wood (96% of households), house construction (52% of households), fencing houses and kraals (74% of households). Very few households eat bush meat (1%), are engaged in selling fuel wood (3%), charcoal burning (18%), and apiculture (0.2%). Also, very few feed animals with pods (39%) and *Prosopis juliflora* leaves (12%). This could also explain why most households preferred complete eradication of the *Prosopis juliflora*. On average 46% of the environmental income is associated with *Prosopis juliflora*. The total value of the environment good or income that relates directly to use *Prosopis juliflora* by the Afar households is about 3 billion birr (151million USD) per year.
- **Impact of *Prosopis juliflora* on crop income:** only three percent of the households interviewed exclusively depend on agriculture and about 40% of the households are at least involved production of at least one crop. This means that even some pastoralists cultivate crops and 90% of the 40% produce their crops through irrigation and only 5% practice rain fed agriculture. Small scale farmers or pastoralist engaged in crop farming pay about 80 birr per week for irrigation. Maize and sorghum were found to be the main crops grown by Afar pastoralists. The costs of labour and irrigation on averaged expressed as percentage of total value of the harvest is about 29% and 7% respectively. The total crop income associated to *Prosopis juliflora* in Afar Region after deducting all cost is approximately 182 million birr (9 million USD) per year.

- **Soil desalinization and Carbon sequestration:** We estimated the value of desalinization by estimating the value of increase in yields associated with desalinization for each crop. Since we did not have experimental results relating to salinity and crop yields for the different crops in Afar Region, we depended on yield response functions for salinity for different crops obtained from the literature reviews. Salinity reduces yield for maize by 25% (BERNSTEIN et al., 1974), sorghum by 16 (MAAS et al., 1986) , onions by 18% (NAGAZ et al. 2012, POSS et al. 1985), tomato by 10-14% (LIU et al. 2014, MALASH et al. 2007, SHALHEVET & YARON 1973) and cotton by 20 (HOFFMAN & RAWLINS 1971, ZHANG et al. 2012). The presence of *Prosopis juliflora* would reverse these negative effects. Data on yields collected from household survey for each group and average value per hectare was used as value of desalinization per hectare and the estimated value of *Prosopis juliflora* from soil desalinization is about 60 million birr (3 million USD). The value of carbon sequestered is 200 million birr (10 million USD) (see proceeding Anna et al. for the details on carbon sequestered).

Negative impacts of *Prosopis juliflora*

- **Impacts on animal production and health**: The results reveal that 13%, 14%, 17% and 20% of the cattle, sheep, goats and camel respectively are either physical injured by *Prosopis juliflora* thorns or affected by *Prosopis juliflora* pods in each household per year. The total milk loss associated to pasture problems created by *Prosopis juliflora* per lactating animal in given lactating period is 10, 1, 5, 4 liters for cattle, sheep, goat and camel respectively. In addition, the total weight associated with pasture problems created by *Prosopis juliflora* per animal is 15, 3, 3, and 8 kilograms for cattle, sheep, goats and camel per year respectively. The total value of milk loss in Afar is animals with pods) about 14 million Birr and total weight loss associated with *Prosopis juliflora* is about 546 million birr. The total loss to animal production is 560 million birr (28 million USD). However, the total loss in livestock production (milk and weight loss) associated with *Prosopis juliflora* is 26 million dollars and the total loss due to animal diseases in terms death due to "Harmaku" disease (resulting from feeding and treatment of *Prosopis juliflora* cases was estimated to be 9.6 million dollars (182 million birr) in Afar Region.
- **Impacts on Human health:** *Prosopis juliflora* is known to inflict physical injuries on human beings and it is associated to rise in malaria cases. Results from our survey reveal that about 80% of households had their member(s) suffer from malaria and 22% had their member(s) physically injured by *Prosopis juliflora* in a given a year. Of the 22% of households, on average two of the household members out of the average of six get physically injured by *Prosopis juliflora* while the average number of household members falling sick of malaria was 4. About 50% malaria cases can be associated to *Prosopis juliflora* invasion. Physical injury had highest number of missed labour days of about 38 days on average compared to 16 days for malaria. However, the costs of malaria treatment per person was 1026 birr (51 USD) which was higher than 266birr (13 USD) which is the costs of treating a person injured by *Prosopis*. The total loss per household per year due to human health is $189 which totals to about to be 470 million birr (23 million USD) per year in whole of afar state.
- **Impacts on biodiversity loss:** One of the main threats of *Prosopis juliflora* in Afar Region is biodiversity loss of mainly pasture production and acacia trees. We use the values of pasture lost as a proxy value for biodiversity. Using secondary data from Farm Africa survey, the value of pasture planted in an area cleared from *Prosopis juliflora* is 1291birr per hectare and the current estimate of *Prosopis juliflora* invasion is about 1000 hectares of land in Afar Region. Thus we estimate that the lost value of pasture due to *Prosopis juliflora* is about 1.04 billion birr (52 million USD).
- **Net present value:** Results from costs benefit analysis reveal that in general the current benefits exceed the costs or losses. Results also show that in the next 30 years the Net loss due to *Prosopis juliflora* without control in the whole Afar Region is approximately 1,735 billion dollars and if

current invasion level is maintained or control is undertaken to maintain the current invasion level, the net benefits in 30 years would be 4.6 billion dollars. Since Afar Region is a pastoral area, we examine impact of distributional impacts of *Prosopis* invasion on pastoralist and non-pastoralists. The results indicate, when the distributional incidences are accounted for, *Prosopis juliflora* invasion negatively affects the livelihood of Afar pastoralists. The estimated net loss without control is 2,791 billion dollars and the net loss if the current invasion level is maintained is 535 million dollars. To secure pastoral livelihood, action is needed but the challenge is whether to completely eradicate or control the invasion. Eradicating *Prosopis juliflora* would also create negative impacts on environment. Results from our analysis of the relationship between *Prosopis juliflora* and climate variables show that *Prosopis juliflora* invasion is significantly and positively associated with relative humidity and temperature. Temperature increase can be associated with reduced plants evaporation and absorption/trapping of solar radiation (Cao et al., 2010). *Prosopis juliflora* invasion is also significantly and negatively associated with solar radiation, evaporation, and wind. These results indicate that *Prosopis juliflora* is achieving the intended objective. Therefore the appropriate action would be control other than eradication.

Participatory management and control of *Prosopis juliflora*

The results from the survey show that about 84% of households preferred complete eradication of *Prosopis juliflora* and mechanical techniques were perceived to be the most cost effective and thus the most preferred method over other methods such as commercialized use of *Prosopis juliflora* pods and charcoal burning by organizing pastoralists in to cooperatives. Moreover, the pastoralists have abandoned the cooperatives and some cooperatives have been completely closed or transformed to other activities such as cereal production. Analysis of cost-effectiveness reveals that:

- A household incurs a loss of 41 USD per year in pod crashing. However, those that burn charcoal earned a net benefit of 420 USD per year.
- Mechanical clearing without using wood was found to result to a net loss of 149 USD per hectare while using or selling wood results to a net benefit of 2 USD per hectare.
- Mechanical clearing while using wood from the cleared land generates negative returns of 111 USD per hectare if households have to dig out the roots.
- Digging out roots which seen as most effective approach is only profitable if the wood is used for charcoal burning or sold and the land is either used for crop production or fodder production.
- Based on the results, we conclude that there is need to encourage and support pastoralists to clear the land, utilize the wood, and the land for crop or fodder production in order to sustain-ably control and manage *Prosopis juliflora*.

4.4 Conclusion

Prosopis juliflora invasion although useful, is a threat to Afar pastoral livelihood and action is needed to reduce the negative impacts. Although the majority of the respondents prefer complete eradication over control, it would result to loss ecological benefits such as carbon sequestration, environmental income, desalinization and crop production as well as negative consequences such as increase wind speed, solar radiation, and evaporation. Therefore, although households prefer complete eradication, it is not an appropriate solution. We recommend control other than complete eradication. The analysis of control measures reveals that mechanical clearing while digging out roots is the most cost effective method over other control methods. However their economic feasibility requires selling or using wood and using land cleared off *Prosopis juliflora* for either crop or pasture production. The advantage is that most households

are willing to participate in crop production as well as pasture farming as a way to ensure that they are food secure and earn income.

The challenge however is that agriculture in the Afar Region is only dependent on irrigation and yet pastoral households have limited access to irrigation water and the few available generators have a low capacity. As stated by the respondents during the focused group discussion, out of 50 hectares cleared near the canal only 4 are cultivated because of low capacity of the generators to pump water. The second problem highlighted by the respondents was that of insecure land rights because sometimes land cleared is taken away from members by government and given to investors. Thirdly, participation of pastoralists land clearing is minimal or limited. Much of clearing is done through mass community mobilization program where the army and police are involved but pastoralists with exception leaders have limited involvement. To enhance the control efforts against *Prosopis juliflora*, there is need to involve pastoralist in land clearing and strengthening communal land rights, strengthening clan institutions as well as providing high powered generators to farmers or household willing to use the land in which *Prosopis juliflora* has been cleared in productive areas along the canals and Awash River.

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5. Households' demand for mitigation of *Prosopis juliflora* invasion in the Afar Region of Ethiopia: a contingent valuation

Mesfin Tilahun, Mekelle University, Ethiopia
Regina Birner, University of Hohenheim, Germany
John Ilukor, University of Hohenheim, Germany

5.1 Introduction

A number of *Prosopis juliflora* species including *Prosopis juliflora* are native to Latin America. However, they have been introduced to the arid and semi-arid regions of Africa in the past two centuries for their beneficial uses. *Prosopis juliflora* was introduced to Ethiopia in the late 1970s in very few agricultural research stations for the purpose of soil and water conservation. Currently, the species is considered as a major threat mainly for pastoral livelihood due to invasive nature. *Prosopis juliflora* has a belligerent invasive nature infesting pastureland, irrigated cultivated lands and irrigation canals causing an irreversible displacement of natural pasture grasses as well as native tree species (KASSAHUN et al. 2004). *Prosopis juliflora* in the Afar Region of Ethiopia has invaded over one million hectares of land. It is estimated that Pastoral and agro-pastoral communities in Ethiopia, Kenya and elsewhere are becoming increasingly concerned about the negative impacts of *Prosopis juliflora*. Its negative effects include the impact of this invasive tree on beneficial native species; encroachment onto paths, villages, homes, water sources, crop- and pastureland; and injuries due to thorns that impacted animal and human health apparently resulting in some human fatalities (MWANGI & SWALLOW, 2008; MAUNDU et al., 2009).

Management of invasive species can be undertaken with the application of mechanical, chemical, and biological control methods. However, the effectiveness of any management intervention requires the full participation and willingness of local communities for the fact that they are the immediate victims of the negative effects caused by invasive species. Thus, this study aimed at assessing the willingness of Afar's pastoral and ago-pastoral rural communities to contribute in either cash or labour for the mitigation of *Prosopis juliflora* invasion using mechanical clearing and biological control methods. It also assesses the socioeconomic factors affecting the households' willingness to pay and willingness to contribute labour for mitigation of *Prosopis juliflora* invasion.

5.2 The contingent valuation

The contingent valuation survey was conducted on a sample of 490 households selected from three districts (Gewane, Amibara, and Awash Fentale) of the Afar Regional State in Ethiopia. In contingent valuation

study, respondents to the valuation survey have to be provided with adequate and accurate information about the hypothetical market situation so that they can make rational decision on their willingness to pay responses. Therefore, we designed a contingent valuation survey that contains four parts.

The first part describes the beneficial uses and negative of *Prosopis juliflora* as well as the rationale for intervention for mitigation of *Prosopis juliflora* invasion. The beneficial uses include fuel wood, charcoal, local construction materials, pods as fodder, and nectar for bee keeping, protection of soil erosion. Whereas the negative effects include encroachment on pastureland and cropland, reducing biodiversity, blocking of key paths and roads used by humans and livestock, increased incidence of malaria, physical injuries on humans and livestock caused by the tough thorn of the tree. Following the description, respondents were asked questions that help to assess their level of understanding of the described beneficial uses and negative effects in comparison to their previous knowledge about the uses and negative effects of the plant. The last section of the first part of the survey deals with informing respondents on the need for mitigation of *Prosopis juliflora* invasion in their village. Respondents were asked to choose from two mitigation policy options, namely complete eradication of *Prosopis juliflora* from all land uses in their village or controlling its further expansion through productive use of the *Prosopis juliflora*. In either case, the objective of the intervention is to improve the livelihood of the rural people in the region through avoiding and/or minimizing the negative impacts of *Prosopis juliflora* and maximizing the benefits through productive use of the tree.

The second part deals with informing respondents about the need to make voluntary cash or free labour contributions for either completely eradicating or controlling further expansion of *Prosopis juliflora* in all land uses found in their village.

The third part contains the contingent valuation questions. We applied a double bound discrete choice contingent valuation questions, which is similar to a two-step auctioning process. In the first step the respondent is asked to answer Yes or No to the initial pre-determined price (bid) in the first question followed by the same question but with higher price (double than the initial bid) if the respondent's answer to the first question is Yes and with lower price (half of the initial bid) otherwise. In contingent valuation survey, respondents have to be allowed to respond zero willingness to contribute values. Therefore, following the double-bound (similar to a two-step auctioning) discrete choice valuation questions, we asked the maximum amount that each respondent is willing to pay and contribute labour using open-ended question. For households who respond zero willingness to pay a follow up question was asked for screening the protest responses from the genuine zero willingness to contribute responses. Five initial bid levels (Table 1) were determined for the willingness to pay as well as willingness to contribute labour based on pilot survey data using open-ended willingness to pay and willingness to contribute labour questions on a sample of 30 households from the same study area. We applied the method of BOYLE et al. (1988) to determine the initial bids. For each initial bid level, 98 respondents were randomly assigned for the main survey.

The last part of the survey contains questions that are used to collect data on the demographic and socio-economic characteristics of the respondent households.

The data analysis of respondents' choice for the valuation questions was based on the concepts in the random utility model (MCFADDEN, 1974; HENEMANN, 1984) and using standard econometric methods applied in contingent valuation studies (HANEMANN et al., 1991; CAMERON & QUIGGIN, 1994; HOLMES et al., 2004; TILAHUN et al., 2013).

Bid	Bid [Initial, Upper, Lower]				Sample size
	Complete Eradication		Controlling Expansion		
	WTP	WTCL	WTP	WTCL	
A	[36, 72, 18]	[5, 10, 3]	[6, 12, 3]	[3, 6, 2]	98
B	[83, 166, 42]	[12, 24, 6]	[14, 28, 7]	[6, 12, 3]	98
C	[125, 250, 63]	[18, 36, 9]	[21, 42, 11]	[9, 18, 5]	98
D	[172, 344, 86]	[25, 50, 13]	[29, 58, 15]	[13, 26, 7]	98
F	[214, 428, 107]	[30, 60, 15]	[35, 70, 18]	[16, 32, 8]	98

Table 1: Bid design for willingness to pay (WTP) in Birr/household/year, willingness to contribute labour (WTCL) in Days/household/year, and number of randomly assigned sample households.

5.3 Results

Households' knowledge and attitude on some elements the valuation

The study indicated that few of the households (11.63%) had previous knowledge about all the beneficial local uses of *Prosopis juliflora* whereas about 93% of the respondent households reported that they were able to learn more from the interview and understood all the beneficial local uses very well. The same proportion of respondents had different levels of previous knowledge that range from not knowing any to knowing all about the beneficial local uses of the plant.

In the case of the negative effect of *Prosopis juliflora*, a little more than a quarter (28.89%) of the respondent households reported that they had previous knowledge about all the negative effects of the plant. Whereas based on the information they get from the interview, 97.35% of them reported that they were able to understand all of the negative effects.

In the case of choice of the mitigation options, majority of the respondents (84.08%) were in favour of the complete eradication of *Prosopis juliflora* from their village whereas only 15.92% were in favour of the controlling of further expansion of the plant through productive use. In terms of choice for mitigation technologies, majority (70.41%) of the respondents preferred mechanical removal of the tree with burning of the root system whereas 17.96% preferred the application of chemical control method. The remaining respondents preferred charcoal production (8.57%), pod crashing (2.65), and biological control (0.41%) methods.

With regard to respondents' perception towards the rules of contingent interventions, 87.76% reported that the requirement of minimum number of volunteers' participation would increase their interest to contribute for the intervention of mitigating *Prosopis juliflora* invasion in their village. In terms of the payment mechanism, 28.37% of the respondents prefer to make their contribution in terms of labour, 28.35% prefer to contribute in terms of cash, whereas the remaining 44.29% are indifferent between paying in cash and contributing in labour terms.

Estimates of willingness to pay and willingness to contribute labour

The upper and lower bound median willingness to pay in cash for complete eradication of *Prosopis juliflora* in the study area were estimated at Birr 246.22 (= USD 12.82) and Birr 203.00 (= USD 10.57) per household per year. For the intervention of controlling of further expansion of *Prosopis juliflora* through productive use, the upper and lower bound median willingness to pay were Birr 67.60 (= USD 3.52) and Birr 41.54 (= USD 2.16) per household per year. In terms of labour, the median upper and lower bound estimates were close to 34 and 41 days per household per year for the complete eradication whereas 25 and 20 days for the controlling of further expansion of the invasive plant. In both willingness to pay and willingness to contribute labour for any of the interventions, the difference between the median and mean values was not statistically significant for each of the models. In other words, the median value was within the 95% confidence interval of the mean.

	Complete eradication		Controlling further expansion	
	Upper bound	Lower bound	Upper bound	Lower bound
Willingness to pay in Birr/hh/yr				
Median WTP	246.22	203.00	67.60	41.54
Mean WTP	253.01(5.74)	219.42(5.46)	68.87(1.03)	41.93(0.91)
95% CI of Mean WTP	[241.74 , 264.29]	[208.69 , 230.14]	[66.84 , 70.90]	[40.14 , 3.73]
Willingness to contribute labour in days/hh/yr				
Median	40.89	33.74	25.43	20.47
Mean	41.65(0.81)	32.51(0.91)	26.03(0.47)	20.64(0.41)
95% CI of Mean	[40.06 , 43.23]	[30.72 , 34.30]	[25.11 , 26.96]	[19.84 , 21.45]

Table 2: Estimates of willingness to pay and willingness to contribute labour for mitigation of *Prosopis juliflora* invasion in Afar.

Both the willingness to pay and willingness to contribute labour for either of the mitigation options are significantly affected by the bid (price level) and the following household characteristics.

- **Bid:** as bid level increases the willingness to pay and willingness to contribute labour decreases.
- **Occupation:** the likelihood to accept higher bids (both in terms of cash and labour contributions) is higher for the pastoral households than non-pastoral households (which include agro-pastoralists, crop-farmers, traders, and civil servants).
- **Off-farm income:** the likelihood to accept higher bids mainly in cash increases with household off-farm income. This indicates that a *Prosopis juliflora* free environment is like a normal good for the respondents whose demand increase with increasing income. In addition, other income source indicating variables (example: livestock product income, crop income) were found insignificant in affecting willingness to pay in cash. This might be because much of the incomes of households from the later sources are in kind whereas off-farm income is mostly in cash that solves their liquidity constraint on which they can depend more for making payments such as for the mitigation of *Prosopis juliflora* invasion.

- **Incidence of physical injury on household members caused by thorn of *Prosopis juliflora*:** households whose members experienced physical injury caused by the thorn of *Prosopis juliflora* were more willing to accept higher bids in terms of both cash and labour than households whose members did not experience such an injury.
- **Level of *Prosopis juliflora* invasion on government land:** the higher the level of invasion of *Prosopis juliflora* on government land the less likely the household is willing to pay higher bids in terms of cash as well as labour for mitigation of *Prosopis juliflora* invasion. This might be because

households have no incentive to contribute for either eradicating or controlling expansion of *Prosopis juliflora* on government owned land. Moreover, the study also showed that households are less willing to accept higher bids at least in the case of the willingness to contribute labour with increasing level of invasion of *Prosopis juliflora* on communal pastureland.

Furthermore:

- **Livestock holdings:** the number of livestock holdings positively and significantly affects households' willingness to pay in cash for either of the mitigation options.
- **Level of *Prosopis juliflora* invasion on croplands:** the higher the level of invasion of *Prosopis juliflora* cropland the less likely the household is willing to pay higher bids in terms of cash as well as labour for the complete eradication intervention. The same variable did not have significant effect on the either willingness to pay and willingness to contribute labour for the controlling further expansion option.

On the other hand, we found that households' characteristics like age, education level, and gender of the household head, and family size were insignificant in affecting willingness to pay and willingness to contribute labour for mitigation of *Prosopis juliflora* invasion.

Taking into account the current population size of 159, 194.00 (CSA, 2013) in the three districts of the study area, an average family size of 6.33 (Table 4), and the lower bound median willingness to pay and willingness to contribute labour estimates, the following amounts of resources could be mobilized for mitigation of *Prosopis juliflora* invasion in the three districts.

- For the campaign of complete eradication of *Prosopis juliflora*:
  - A minimum of Birr 5.11 million (= USD 266 thousand) and a maximum of Birr 6.19 million (= USD 325 thousand) could be mobilized as a voluntary cash contribution per year.
  - A minimum of 849 thousand and a maximum of 1.03 million labours could be mobilized as a free labour contribution per year. This is equivalent to Birr 3.4 to 4.12 million (=USD 333 to 404 thousand) at the average per capita off-farm income of Birr 4.00 that we found from this study. Our estimate for the value of labour contribution is a very conservative and the aggregate estimated value would be much higher if we consider the daily wage rate in rural areas of the study area.

- For the campaign of controlling of further expansion of *Prosopis juliflora*:
  - A minimum of Birr 1.04 million (= USD 54.4 thousand) and a maximum of Birr 1.70 million (= USD 88.6 thousand) could be mobilized as a voluntary cash contribution per year.
  - A minimum of 515 thousand and a maximum of 640 thousand labours could be mobilized as a free labour contribution per year. This is equivalent to Birr 2.06 to 2.56 million (=USD 202 to 251 thousand) at the average per capita off-farm income of Birr 4.00 that we found from this study.

5.4 Conclusion

Prosopis juliflora invasion creates a significant threat to pastoral and agro-pastoral livelihood system in the Afar Region of Ethiopia. Unless action is taken to mitigate the threat, the region as well as the country is unlikely to meet its development goals of improving pastoral and agro-pastoral livelihood and reducing poverty in the region. This study indicated that the pastoral and agro-pastoral communities in Afar are

willing to make cash and labour contributions for well-organized actions that aim to mitigate the threat that *Prosopis juliflora* invasion is causing on their livelihood. Most households in the study area prefer the complete eradication of the invasive plant than the option of controlling the plant through productive use. Moreover, the cash and labour contributions that the households are willing to make for the complete eradication option are higher than the contributions for the controlling of further expansion of the invasive plant. However, in any effort for mobilizing the cash and labour resources and attain a successful intervention, it is important to consider the following:

- The pastoral and agro pastoral communities should be provided with full information on the negative effects as well as beneficial uses of the species,
- The mobilization of the contributions should be on voluntary basis,
- There should be a strong and sustainable institution that can create the awareness, mobilize the communities, and design appropriate management plan,
- Before a mitigation intervention, a management on how to utilize the land that is cleared from *Prosopis juliflora* and the cleared biomass of *Prosopis juliflora* is important as an incentive for the communities.
- Training on different mitigation technologies as well as trainings on charcoal making to local communities is also important in empowering local communities to benefit from the beneficial uses of the invasive plant while controlling its expansion and mitigating the negative impacts.

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5.6 Further Information

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6. Livelihood Diversification Option and its Determinant

Mohammed Jemaneh Seid, Afar Pastoral and Agro-Pastoral Research Institute, Ethiopia
Adam Bekele, Awash Melkassa Agricultural Research Centre, Ethiopia

6.1 Introduction

Pastoralists are estimated to constitute 11 percent from the total population of Ethiopia (CSA, 2011). However, they exhibit the highest rates of poverty and the lowest human development indices. Pastoralists raise 50-70 percent of their livelihood from livestock. However, only 1.5 million (27 percent) earn good revenue from livestock (CSA, 2007). Pastoralists are exposed to the vagaries of nature that add to their vulnerability to climate changes including drought and dwindling pasture land by invasive alien species (IAS). Over 700,000 hectares of prime grazing land and cultivable land following the Awash River is currently either invaded or at risk of invasion from *Prosopis juliflora* in the Afar Region, (USFS, 2006 cited in DUBALE, 2006).

Despite *Prosopis juliflora* has the negative impact and different perceptions among the large part of the community (farmer and pastoralist), it is used as an income source for the livelihood of part of the community including daily laborers and fuel wood and charcoal producers. Therefore, eradication of IAS may have unfavorable effect on livelihood strategies that the community pursues. Similarly, PASIECZNIK et al. (2001) indicate that *Prosopis juliflora* was introduced 25 years ago to provide fuel and fodder, but has since become an invasive weed, threatening, rather than improving local livelihoods. It is now being turned into a valuable resource, and is starting to provide the rural poor with a ready cash income and numerous indirect benefits. At early stage, expensive eradication and biological control of *Prosopis juliflora* was considered the best option. However, latter a DFID project (R7295) was the first to collate the global knowledge on *Prosopis juliflora*, concluding that eradication was not only impossible but also unnecessary when improved management, utilization and marketing could provide incalculable benefits to rural communities if the knowledge contained therein was applied effectively, while also effectively controlling further spread (PASIECZNIK et al., 2001).
On the other hand, BARRETT et al. (2001) suggest several reasons why households choose to diversify, and these can be classified as "push" and "pull" factors. Diversification due to "pull" factors is a response by households to exploit economic opportunities that are created by local economic and population growth, proximity to urban markets and improvements in infrastructure. In contrast, "push" factors are those that force households to diversify as a coping strategy. Diversification by poor households in developing countries is usually a response to "push" factors.

Hence, this study highlights pastoral livelihood determinants associated with pastoralist's perception on *Prosopis juliflora* in Gewane district of Afar Regional State, Ethiopia.

6.2 Research Methodology

Study Area, Sampling Technique and Data Source

This study was carried out in Afar Regional State, Gewane district of five selected kebeles which were highly invaded by invasive species weed, *Prosopis juliflora*. Gewane district covers an area of 86,796 square kilometers. From the total 31,313 people who live in the district, 25,331 live in the rural area and the rest 5,982 people live in urban area. Both pastoralism and agro- pastoralism are the main stay of the district and they provide the largest share of the livelihood for the population. Among 10 kebeles of the districts, two kebeles are categorized as pastoral and eight as agro-pastoral livelihood zones. Gewane district is highly invaded by *Prosopis juliflora* and several plant species have been endangered in areas infested by this IAS. Several animal species have migrated to other areas since they were not able to move around freely because of the dense tickets of *Prosopis juliflora* (ARPARDB, 2008).

The research design followed a three-stage sampling procedure. In the first stage, Gewane district was selected purposively. In the second stage, 5 kebeles (Gebeyaborra, Amassabure, Urrafita, Gelilladora and Bereiforra) were randomly selected. Finally, a total of 150 respondents were selected randomly based on probability proportional to size of the kebeles.

In this study, both primary and secondary data were used. The data had both Quantitative and Qualitative nature. Primary data were collected from sampled respondents through pre-tested structured questionnaire and interview. Additionally, written documents including those from agricultural and pastoral rural development bureau and recent research works about the study area were used as secondary data.

6.3 Data Analysis

Determinants of Pastoral Livelihood Diversification

Two-step instrumental variable Tobit model

To assess the factors influencing pastoral livelihood diversification, two step instrumental variable Tobit regression model was employed on the different means of livelihood defined by Simpson's diversification index as dependent variables.

Computing the index

The diversification index, the dependent variable, was computed using Simpson's diversification index formula (PATIL & TAILLIE, 1982) given by:

$$SDI = 1 - \sum_{i=1}^{n} \left[\frac{M_i}{M_T}\right]^2 \quad i = 1,2, \ldots, n \qquad (1)$$

Where;

M_i= income from each activity,
M_T= households' total income and

n = sources of income

The above indices assumed a value of 0 when their respective upper limit = 1 and a value of 1 when their respective upper limit = ∞. Closeness to 0 implies decreasing diversification whereas closeness to 1 implies advancement for perfect diversification.

Estimating Two-step Tobit model (ivtobit)

The dependent variable (SDI) was regressed on the hypothesized explanatory variables by two-step Tobit model (ivtobit). Tobit model, the censored normal regression model, is one with censoring from below at zero where the latent variable is linear in regressors with additive error that is normally distributed (CAMERON & TRIVEDI, 2005).

Thus, it takes the form:

$$Y^* = X'\beta + \varepsilon, \qquad (2)$$

Where; in our case

Y_i is the calculated value of Simpson index of diversity for each household, and

x_i are explanatory variables expected to influence the dependent variable

The association between SDI and household perception must be further investigated. Even if SDI depends on household perception about *Prosopis juliflora*, it is not exogenously given since it is determined in part by SDI. Such correlation or association between regressors and errors (endogeneity) lead to inconsistent parameter estimation. CAMERON & TRIVEDI (2005) suggest the instrumental variables estimator as a standard solution for inconsistent parameter estimation caused by endogenous regressors. Hence, in our case a suitable instruments for household perception is a variable that is correlated with household perception but indirectly affect SDI.

If Tobit model with endogenous regressor that is completely observed, then Y^* is fully observed, so $Y_2 = Y^*$, whereas we observe $Y_1 = Y_1^*$ if $Y_1^* > 0$, $Y_1 = 0$ otherwise.

The model becomes

$$Y_1^* = \alpha_1 \beta_1 + X_1'\beta_1 + \varepsilon_1 \qquad (3)$$

$$Y_2 = X'\pi + \nu \qquad (4)$$

Where the first equation is the structural equation of interest and the second equation is the reduced form for the endogenous regressor Y_2. Again note that here Y_2 is continuous, not discrete. For joint normal errors $\varepsilon_1 = \gamma\nu + \xi$, where ξ is an independent normal error, so

$$Y_1^* = \alpha_1 \beta_1 + X_1'\beta_1 + \gamma\nu + \xi \qquad (5)$$

Whereas, a two-step estimation procedure calculates predicted residuals $\hat{v} = Y_2 - X'\hat{\pi}$ from OLS regression of Y_2 on X and then obtains Tobit estimates from the model as follows:

$$Y_1^* = \alpha_1 Y_2 + X_1'\beta_1 + \gamma\hat{v} + e_1 \qquad (6)$$

Where, the error e_1 is normally distributed.

A test for endogeneity of Y_2 can be implemented as a Wald test of $\gamma = 0$ using the usual standard errors from a Tobit package. A Wald test on exogeneity is used to test if the variable (household perception in this case) needs to be instrumented. This test is an extension of the auxiliary regression to implement the Hausman endogeneity test in the linear model. If the null hypothesis is rejected then the aforementioned second-step Tobit regression yields consistent estimates of α_1 and β_1, but standard errors then need to be adjusted because of first-step estimation of the additional regressor $\hat{v}$ CAMERON & TRIVEDI (2005). Therefore, to test whether the applied ivtobit estimator, is consistent and more efficient than an alternative Tobit estimator, Hausman's model specification test was also employed.

6.4 Result and Discussion

To achieve the intended objectives, the researcher employed both descriptive and econometric analysis. First, to assess the factors influencing the perception of the household, perception index was developed on the damaging effects of the *Prosopis juliflora* species in a likert scale fashion and regressed to the hypothesized explanatory variables. Finally, to assess the factors influencing pastoral livelihood diversification strategies, instrumental variable two-step Tobit regression model (ivtobit) was employed on the different means of livelihood diversification strategies defined by Simpson's diversification index as dependent variables.

The survey findings showed that household perception accounted 50.7% disfavor the species, 24% reflected neutral/moderate feeling and 25.3% favor the species. Moreover, this variable was used to form a category of other variables to compare values between each category. A significant difference was observed with past and present perception of pastoralists about the species. The area was repeatedly threatened by drought and natural calamity. Access for credit, appropriate technology instrument, improved seed and fertilizers were not available for the pastoralists to combat the hardship. With low infrastructure, the above problems worsen pastoralists living. Pastoralists practice different coping mechanisms like migration, diversification, loan and aid. Thus, livelihood diversification, distress-push diversification, seems their coping strategy for the prevailed risks in the area.

Determinants of pastoral livelihood strategy

Two stages instrumental variable Tobit regression (ivtobit)

For the purpose of this study, the econometric estimation of the determinants of SDI (Simpson diversity index) was conducted using two stages instrumental variable Tobit regression (ivtobit). Table 2 represents results of Two-step Tobit with endogenous regressors (instrumental variable Tobit model) for factors or determinants that influenced the dependent variable Simpson diversity index (SDI) and these were used for variable interpretation. Household perception (HHperc) is instrumented by the variables: sex, education level, drought and experience on *Prosopis juliflora* utilization. The findings of the econometric estimation using Simpson's diversification index as dependent variable support to significant linkages with

household characteristics. Age of household head and Training were negatively influence the outcome variable. But positive and significant sign was observed for the determinants; adult equivalent, TLU per adult equivalent, access for technology, household perception, and Hectare of land cultivated by the household. The latter factors increase the levels of household diversification.

Conclusion and Policy Recommendation

Promoting income diversification and enhancing pastoralists' access to off-farm activities are essential to support equitable rural development, since staying on livestock alone cannot sustain a sufficient livelihood. As the analysis has shown, this requires improvement in professional support and basic training and appropriate extension contact. Likewise, provision of technology instrument with least cost, infrastructure like road, electricity, and accessible market and credit are the other essentials for utilization and enhancing income gain from those activities. Hence, the technology instrument needs to be incorporated with basic training and the provision of those physical and market infrastructures in rural area. Moreover, market restriction has to be either removed or reduced the barriers faced for households and private investors if they want to engage in commercialization of the product.

The absence of effective implementation of the regulation issued to control and manage the species seemed the other factor for *Prosopis juliflora* invasion increment. All level of executing entities who are assigned under the rule to coordinate activities need to reconsider their role and other concerned bodies should support them for the implementation of the regulation.

Livelihood diversification, which had a key role in enhancing agricultural productivity and self-sufficiency, was crucially affected by household perception. Policies aimed at promoting farm-level productivity and self-sufficiency need to emphasize this interdependency which has critical role for improving pastoralists' livelihood. In addition, the individuals, private groups, NGO as well as policy makers should work towards enhancing household awareness on the uses of productive utilization of *Prosopis juliflora* as one of the major controlling mechanism for further species invasion and to fight against drought and livelihood insecurity which are repeatedly occurring in the area.

Acknowledgement

The author is indebted to the Rural Capacity Building Project (RCBP) for funding the research expenses through Afar Pastoral and Agro-Pastoral Research Institute (APARI).

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6.7 Appendices

Table 1: Households characteristics (categorical variables) based on perception about *Prosopis juliflora*

Categorical variables		**Household Perception**						**Total**		χ^2 *test*
		Not good		**Neutral**		**Good**				
		Fre.	**%**	**Fre.**	**%**	**Fre.**	**%**	**Fre.**	**%**	
Sex	**Female**	19	25.0	17	47.2	21	55.3	57	38.0	11.69*
	Male	57	75.0	19	52.8	17	44.7	93	62.0	
Education level	**Illiterate**	66	86.8	31	86.1	35	92.1	132	88.0	0.82
	Literate	10	13.2	5	13.9	3	7.9	18	12.0	
Marital status	**Single**	12	15.8	6	16.7	7	18.4	25	16.7	11.33**
	Married	62	81.6	26	72.2	23	60.5	111	74.0	
	Divorced	1	1.3	2	5.6	3	7.9	6	4.0	
	Widowed	1	1.3	2	5.6	5	13.2	8	5.3	
Extension service	**no**	6	7.9	6	16.7	10	26.3	22	14.7	7.02**
	yes	70	92.1	30	83.3	28	73.7	128	85.3	

Technology	**no**	53	69.7	21	58.3	22	57.9	96	64.0	2.202
	yes	23	30.3	15	41.7	16	42.1	54	36.0	
Total		76	50.2	36	24.5	38	25.5	150	100	

Note; *, ** and *** indicate significant at10%, 5% and 1% probability level respectively
Source: Survey data analysis

Table 2: Two-step tobit with endogenous regressors

SDI= Dependent Variable **Instrumented: Household perception**			
Variables	**coefficient**	**SE**	
ageHH	-.001*	.001	
Adultequi	.056***	.014	
Tluperadequ	.014***	.003	
Tfarmy	.004	.023	
Landccpradt	.302***	.100	
Technology	.110*	.061	
Training	-.011	.064	
Expli	.003	.002	
Expecc	.0059	.014	
HHperc	.202***	.053	
_cons	-.481**	.210	
Number of obs	150	left-censored observations at sdi2<=0	51
Wald chi2(10)	135.48	uncensored observations	99
Prob > chi2	0.0000	right-censored observations	0
Wald test of exogeneity: chi2(2) = 5.44 Prob > chi2 = 0.0196			
Hausman Specification Test **H_0: difference in coefficients not systematic** Chi2(10) = 32.28, p-value = 0.0004 ▸ ivtobit superior to OLS and tobit			

Note: *, ** and *** means significant at10%, 5% and 1% probability level respectively
Source: Author's estimation

Table 3: Tests of endogeneity: HHperc (household perception regarding the species)

Wu-Hausman F test H0: Regressor is exogenous	**Durbin-Wu-Hausman chi-sq test** Ho: Regressor is exogenous
Variables: percption	Variables: perception
F(1,138) = 3.11	Chi-sq(1) = 3.31
P-value = 0.079	Prob > chi2 = 0.068
Regressor exogeneity assumption of H_O is rejected	Regressor exogeneity assumption of H_O is rejected

Table 4: Model Specification and Over identification Test

Hausman Specification Test	**Test of over identifying restrictions**
H_0: difference in coefficients not systematic Variables: fitted values of SDI	H_0: Instruments are uncorrelated with the error term / the instruments are valid/.
Chi2(10) = 32.28	Amemiya-Lee-Newey minimum chi-sq statistic Chi-sq(3) = 4.68
Prob> chi2 = 0.0004	P-value = 0.196
Assumption of H_0 is rejected since ivtobit model is superior to OLS and tobit.	Valid instruments assumption of H_0 is accepted

Source: Author's estimation

7. Gender aspects of *Prosopis juliflora* spread in Baadu area, Afar Regional State, Ethiopia - Perceptions, impacts and coping strategies

Helena Inkermann, University of Bonn, Germany

7.1 Introduction

The Afar Regional State located in the north-eastern lowlands of Ethiopia is heavily invaded by *Prosopis juliflora*, an invasive species originally coming from South and Central America. Invasive plants can cause extensive environmental, economic and social harm which should be assessed in a gender sensitive way since men and women utilize resources differently. In a pastoral society strict gender roles can be found which influence the work load and work task of men and women, power relations, the role of women in decision making processes, as well as their access to resources. Against the background of these different gender roles this paper argues that there are gender-specific impacts related to the spread of *Prosopis juliflora*. Often, women have less ownership rights then men do and also less access to resources. A gender perspective can improve our understanding of the socially differentiated impacts of invasive species as well as the effectiveness of future management interventions. Gender sensitive approaches in managing invasive species can contribute to more social equity, taking the importance of women as social actors into account (FISH et al. 2012; BORMANN & ALEMARIYE 2013).

In the past, research failed to include the gender dimension of *Prosopis juliflora* invasion. This paper deals with gender-sensitive questions. To what extent is the vulnerability of women changing due to the invasion of *Prosopis juliflora*? How do the perceptions, the impacts and the coping strategies of men and women differ? What kinds of differences exist among the group of women? To what extent does the invasion influence gender roles? The following paper presents the results of a case study located in Baadu area in the middle Awash Basin (Fig. 1), in April 2014. The Baadu area has been heavily affected by the spread of *Prosopis juliflora*, leaving almost no grazing areas for the livestock of the pastoralists (see AYANU et al., proceedings). In the case study, which was part of a social impact assessment implemented by the University of Bonn in collaboration with GIZ and Bayreuth University, a qualitative approach was used to identify gender differentiated perceptions, impacts and coping strategies.

During four weeks of field work a sample of 30 key informant interviews was selected, representing men and women of different age and social groups from rural and urban areas. In addition, interviews with representatives from the woreda level as well as NGO members were taken.

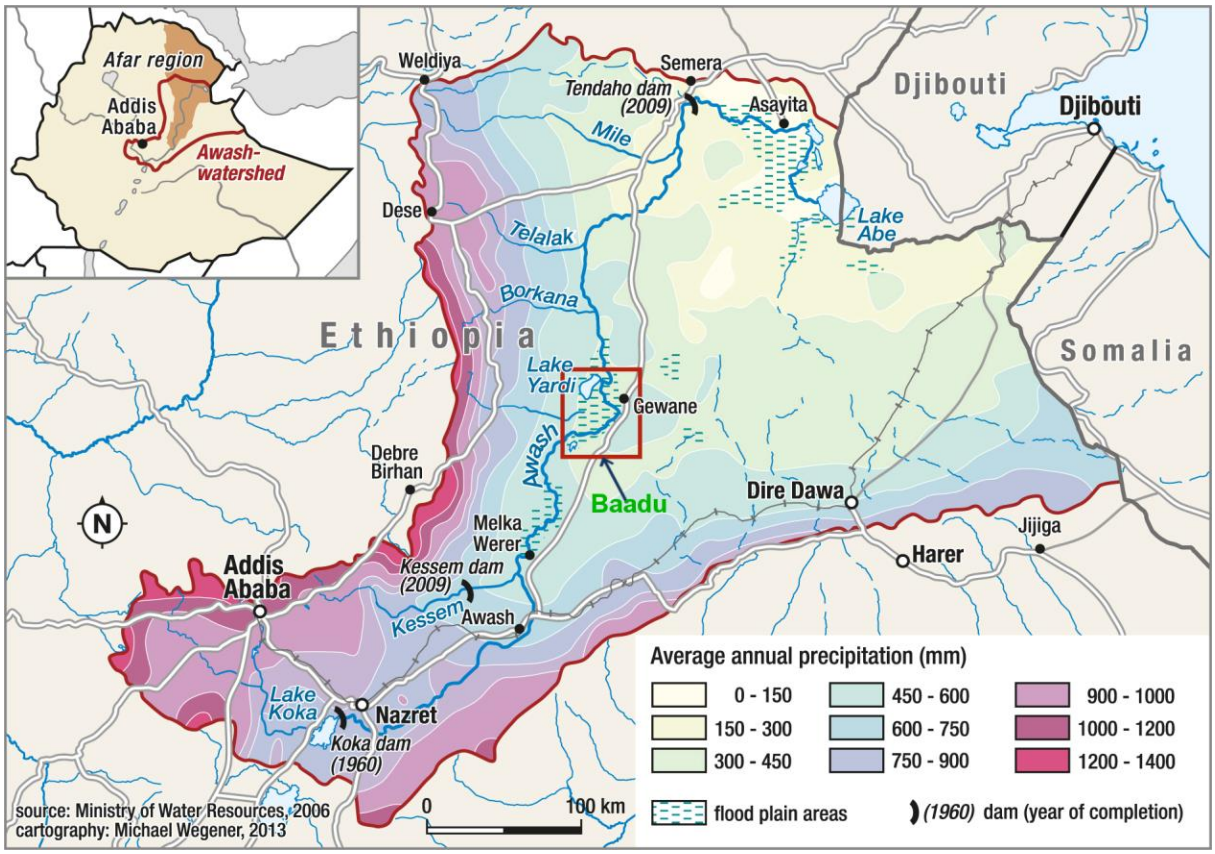

Figure 1: Location of the study site in the middle Awash Basin (AYANU et al., 2014)

7.2 Key findings

Perceptions

Analyzing the perceptions of the spread of *Prosopis juliflora* there are some perceptions shared by men and women. Others differ between the sexes and can be directly linked to the different gender roles. Both groups perceive the invasion of *Prosopis juliflora* as a curse of Allah, due to misbehavior of their ancestors. Generally, the Afar think of Allah as the one who brings hardship and/or good times, depending on their well-practice of the Islamic religion. In the case of *Prosopis juliflora* the rage of Allah concerns everybody regardless of their sex. The local people call *Prosopis juliflora* either Derg Hara or Woyane Hara, since it was the time of the Derg regime and the Woyane rebellion when *Prosopis juliflora* was first planted and started to invade.

The spread of *Prosopis juliflora* needs to be seen in a broader context of a set of problems affecting the Afar pastoralists. Besides the invasion of *Prosopis juliflora* they face a violent conflict with the neighboring Issa pastoralists, the flood regime of the Awash River has changed and the expanding irrigation agriculture (Fig.2) as well as the growing charcoal business are fostering ecological changes (see Detona, proceedings). The ranking of these problems differs between men and women. Generally, *Prosopis juliflora* is perceived as the main reason for decreasing herd sizes since it leads to the loss of dry season grazing areas and animal diseases like Harmaku (see following chapter). Besides the spread of *Prosopis juliflora*, men mention the conflict with the neighboring Issa pastoralists as a main problem. The Issa violently pushed them from most of their traditional rainy season grazing areas during the last 50 years, but while men say that it is possible to recover from Issa incidents, they say that it is impossible to recover from *Prosopis juliflora.* Next to the problems *Prosopis juliflora* is causing to the livestock, women mainly name household problems which are related to the invasive species, like health issues and food insecurity.

These perceptions are closely linked to the work tasks of men and women. Generally, men as well as women feel destitute and they stress that they need help from the outside to fight the invasive plant.

The invasion of *Prosopis juliflora* is positively perceived by very few Afar. Most of them are young men who are engaged in the charcoal business, a growing business sector in the area around Gewane and Mataka (see Fig. 2). People who are successful in the business are likely to make a lot of money and improve their livelihoods (DETONA, proceedings).

While gender-specific differences in perception might be less obvious, there is a significant difference in relation to the dominant livelihood system. Pastoralists living far away from permanent settlements who depend heavily on their livestock perceive the *Prosopis juliflora* invasion extremely negative, while Afar living in more urban areas and who are more involved in non-pastoral activities do not feel as strongly about the *Prosopis juliflora* spread. They depend less on the environment and are therefore not affected as heavily as the pastoralists.

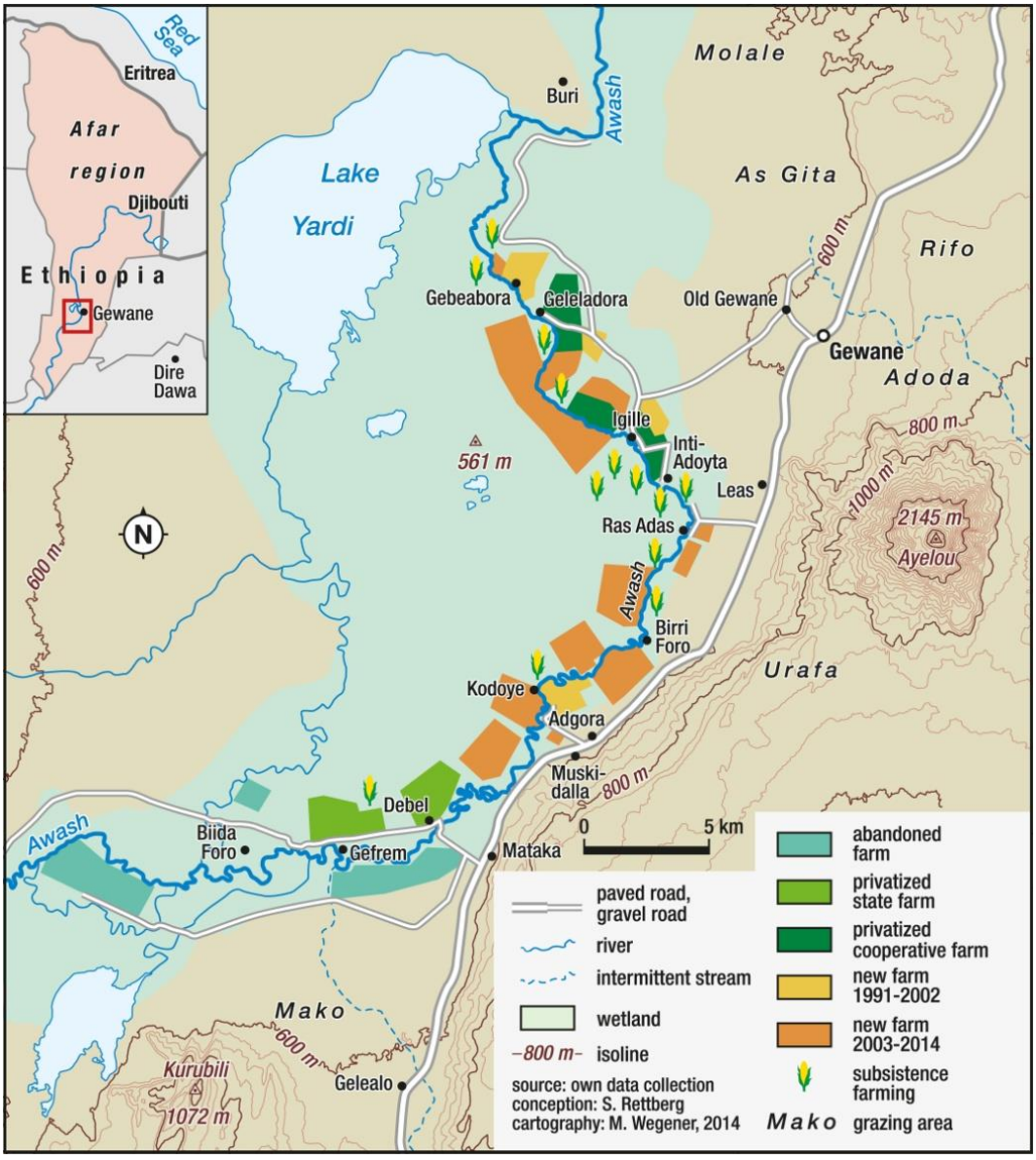

Figure 2: Expansion of irrigation agriculture (RETTBERG, 2014)

Impacts

Most men and women outline that *Prosopis juliflora* does not discriminate but that everybody is affected in the same way. Pastoralists do not consider themselves as individuals but normally look at the bigger picture of their whole family or even the clan. Therefore, they outline that the impacts of *Prosopis juliflora* spread concern men as well as women in the same way.

Nevertheless, a deeper analysis reveals some important differences. The work tasks and the work load of pastoralist men and women are different. Looking into the Afar pastoralist society, a typical work task for men is for example, to deal with large livestock production which implies traveling with the animals to faraway grazing areas. Afar women on the other hand are in charge of domestic chores such as nourishing the family, collecting water and fire wood, looking after small livestock (sheep and goats) as well as building traditional houses. Those work tasks lead to gender-different interactions with the environment and use of resources and therefore impacts need to be distinguished between men and women.

Prosopis juliflora invaded most of the dry season grazing areas in Baadu, the rainy season grazing areas also start to be affected by the spread. The decrease of grazing areas together with animal diseases lead to the decline of the livestock herd sizes. Less livestock means that the food security is shifted from periodic food insecurity to a chronic food insecurity of pastoralists in Baadu, since they used to live purely from their livestock and livestock products. The food insecurity is worsened by the disappearance of indigenous trees, of which the roots and fruits were used as supplementary food supply. Food shortage always hits women hardest since they are the ones responsible for the provision of food to the household. Also, they rank last in the order of taking their meals; therefore they will be affected first by mal nourishment.

In the interviews health issues for human beings as well as for their livestock were named. The health issues for animals are on one side connected to the noxious thorns of *Prosopis juliflora* which cause injuries, mainly to the feet of animals. In most cases the injuries are followed by serious infections. On the other side, animals feeding on too many pods of *Prosopis juliflora* end up with digestion problems. This animal disease is called Harmaku and leads to the death of livestock. Harmaku deforms the jaw of animals (Fig.3) afterwards they become thin and die of malnutrition.

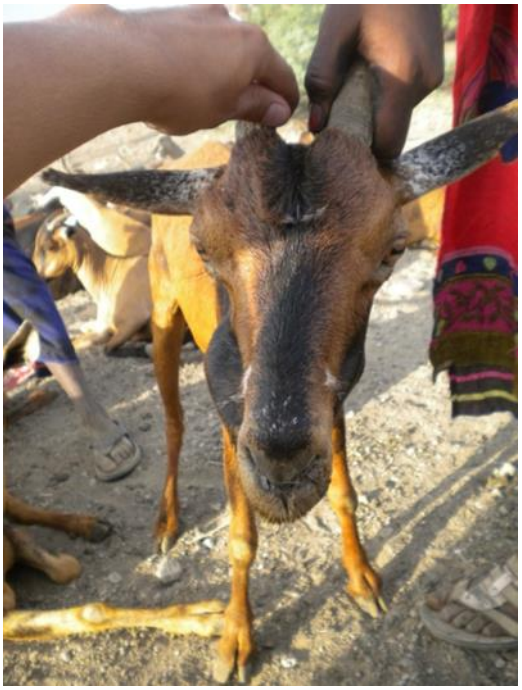

Figure 3: Deformation of the jaw of a goat suffering from Harmaku (INKERMANN, 2014)

For human beings the thorns of *Prosopis juliflora* create a serious risk of injury. When men and women are herding the animals they risk stepping into the thorns, some people even went blind from the thorns pinching their eyes. Women also risk to be injured while looking for fire wood or fetching water. The thorns of *Prosopis juliflora* cause serious infections which are mainly taken care of by women. Even though there is no traditional treatment women try to take care of the infections with saltwater. In very serious cases they consult health centers. The treatment of injuries and infections increase the already heavy work load of women. Women injured by *Prosopis juliflora* sometimes have to rest in order to cure the injury. Not being able to fulfill their daily household chores leads to a severe problem for the whole family, since they depend on women serving meals and taking care of the provision of water.

The mobility patterns of men and women are heavily impacted by the spread of *Prosopis juliflora*. Men who are moving to faraway places with camel and cattle are impacted by the spread of *Prosopis juliflora* since most of the dry season grazing areas are covered by the invasive species. In the past men travelled over long distances with the livestock only staying for short periods at the grazing areas. Today, they have fewer places to go, therefore, they stay at the same grazing area for longer time periods, moving less. Women are in charge of the small livestock like goats and sheep also they take care of household chores. All these activities take place in close distance around the settlement, the places which are densely covered by *Prosopis juliflora.* In some cases their pathways and short cuts are blocked, some women even reported that wells were blocked by *Prosopis juliflora*. Most of the time women go around the plants, only when the spread becomes too aggressive the plant will be removed.

Afar who live in the towns are less impacted by the spread of *Prosopis juliflora* since their livelihood is less attached to the management of natural resources, they do not have to fetch water or search firewood. Pastoralists on the other hand, generally have fewer options to cope with the invasion of *Prosopis juliflora* and are therefore especially vulnerable.

Coping strategies

In order to cope with the impacts arising with the spread of *Prosopis juliflora* the Afars men and women come up with different kinds of strategies. In the following, gender-specific coping strategies will be named. An analysis of the impacts of these coping mechanisms on gender roles and relations will be made afterwards.

Due to the increasing food insecurity, many pastoralists drop out of their traditional lifestyle. Since they are no longer able to survive on the basis of their livestock, they diversify their livelihood by engaging in income earning activities. The shift from a purely pastoral life to more diversified livelihood strategies is mostly connected to a process of sedentarization in places where income can be generated and markets can be accessed (e.g. roadsides, urban settlements, around farms).

Both, men and women engage in income earning activities, still, the number of women engaged is generally higher. The main reason for pastoralists to drop out of their traditional pastoral livelihood is food insecurity. Men engage mainly in administrative jobs, they work as daily laborers, sale livestock or agricultural products. The work of women seems to differ in every settlement depending on the resources available. Most of the women's work is labor intensive and demands high physical strength. Products are sold along the road side, some to other pastoralists living in the area. Not all of the incomes earning activities are new, but the number of women engaging in them is increasing. While women in Mataka produce mostly Gedayta, women in Birri Foro and Leas started to grow maize on small farms (Fig. 4 & 5). Women and men also work on private farms. Working in daily labor at agricultural farms is connected to a high dependency on the farm owners. Women also open little coffee and tea shops along the roadside (Fig.6), they sell chat,

injeera and cold drinks, they produce fire wood which as well is sold along the roadside. Men picking up jobs to contribute to the households income generally do not keep their pastoralist work tasks. Women on the other hand still need to fulfill their daily household chores while also working in other income earning activities. Women as the ones responsible for the household's food security therefore face more a different kind of pressure to pick up work to generate income to cope with the household's food insecurity.

The engagement of women into income earning activities has an ambivalent structure. On the one hand, it increases the vulnerability of women. Taking up new activities to add up to the households' financial situation increases their work load which has already been high before. Also, the activities women pick up are in most cases physically intensive which again adds up on their work burden. On the other hand, by engaging in income earning activities, Afar women have the possibility to access money. By doing so, women increasingly take over the role of bread winners within the household form their husbands who become partly dependent on their wives. This development leads to a new role of women in decision making processes within the household and an empowerment of women in general. This development is supported by efforts of the Women's Affairs Office at the woreda level and several NGOs which are teaching the women about their rights. Even though, this development is still small and especially going on in the urban areas along the road side, can be seen that the role of Afar women in the society is changing.

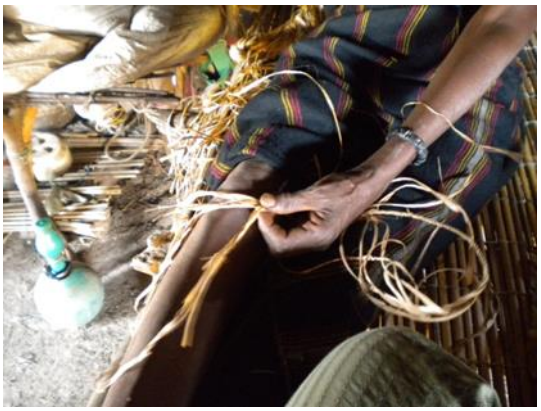

Figure 4: Women producing robes for her Gadeyta mats (INKERMANN, 2014)

Figure 5: Maize harvest of female headed household (INKERMANN, 2014)

Figure 6: Woman in her little shop along the road side, selling tea, coffee, and little snacks (INKERMANN, 2014)

Figure 7: Charcoal sold along the roadside in Mataka (INKERMANN, 2014)

Another coping strategy which is specific for Baadu is the production of charcoal (see DETONA, proceedings & Fig. 7). The charcoal business has many positive affects for those involved but can have negative aspects especially for women who live close to the charcoal production sites. Mostly, young men engage in the charcoal business, therefore, they are the once who benefit most. Very few women also engage in the charcoal business. Still, they report that the business is extremely dangerous for women. One problem concerns the charcoal workers who do not obey to orders given by women. To guarantee a successful charcoal production process, the charcoal producers need to be controlled during the production process. Women face sexual harassment while going to the forest to check on the performance of the workers. The few women engaged in the business reported that they need a male counterpart to successfully do their work and be able to protect themselves against harassment.

Also rape incidents have increased with the growing charcoal trade. Afar women living close to the charcoal production sites deep in the rural areas feel at risk from charcoal workers who are coming from the highlands and do not share the same traditional background as the Afar people. The Afar women are afraid of them since they have already experiences sexual harassment of many kinds or have heard of the harassment cases. In the past any kind of sexual harassment taken on Afar women was revenged by their husbands and family. Women report that this protection mechanism, which frightened possible attackers, is not functioning anymore. The number of charcoal workers has become very high and the workers protect each other. Those who attack Afar women mostly disappear before the Afar men can take revenge. Afar men report that it is impossible to retrace the offender and take revenge. The failing protection mechanism

increases the feeling of insecurity among Afar women. New spaces of fear are created that completely change the daily activities of the women who live close to the charcoal production sites. To overcome the threat of sexual harassment, women organize in groups or stay close to the Afar men. Activities they used to do on their own, like fetching water, are now done collectively in order to feel safe.

The impacts of Prosopus juliflora spread show a high vulnerability of people who live in the rural areas. While an empowerment process of women is taking place in the urban areas along the roadside, deterioration of the situation of the women in rural areas, especially in the charcoal production areas, can be observed. Pastoralist women can be identified as the most vulnerable group in Baadu.

7.3 Conclusions and recommendations

The paper outlined that the invasion of *Prosopis juliflora* has a high impact on gender aspects and that there are clear differences to be made between the perception, impacts and coping strategies of men and women. Looking into the gender differentiated perceptions of *Prosopis juliflora* a close connection to the religious believe and lifestyle of the people was observed. The main differences were seen in the raking of problems the Afar pastoralist society is facing. The focus on impacts of *Prosopis juliflora* invasion on men and women showed that there is no direct differentiation made by the locals. The observation of impacts from a research perspective illustrated that the impacts on women are generally higher than on men, because they are affected in their everyday life activities. Also, women are the ones who suffer under food insecurity at first hand. Pastoralists, especially female pastoralists were identified as the most vulnerable group in Baadu. The research on coping strategies showed that the existing coping strategies lead to positive developments as well as threats for women. The positive development is seen in an empowerment process of women. This positive development is supported on an administrative level. Threats occur in connection to the rapidly growing charcoal business, protection mechanisms do not function in the known way anymore creating new areas of fear. The paper also stressed that differences need to be made within the group of women who cannot be seen as a homogenous group. A clear differentiation needs to be made between women living in rural areas and those who live along the roadside. Women living along the roadside profit from the given access to the markets while those women living in the rural areas, still living a purely pastoralist live, do not have such options to cope with the problematic situation turning the negative into the positive. Therefore, Afar women in rural areas can be identified as the most vulnerable group in Baadu.

In order to come up with measures to control or eradicate *Prosopis juliflora* in Baadu, there is a need for a clarification of administrative responsibilities. A first effort has been made by the regional government of Afar which came up with a guideline in 2011. Besides identifying responsibilities this guideline shows a clear motivation to include women in the process. Women should be identified as important social actor whose knowledge and experience is absolutely needed in order to be able to control the invasion. Somehow, this guideline has not been implemented. Any measure planned should take ideas from this guideline.

The ongoing empowerment process which is changing the role of women and giving them a new stand in decision making process should be assisted. Advice can be taken from the Women's affairs office and NGOs like Rohi Wadu in Awash who can share from their long years of experience.

On a more general basis, experiences which have already been made on the control and eradication of *Prosopis juliflora* should be studied and taken advice from. A land use plan could help to clearly identify the use of specific sites for specific activities. The land use plan needs to be developed with the help of clan

leaders, respecting the traditional boundaries of clan areas. Interests and options of women should be included in the process. Lastly, all measures planed should be analyzed concerning their effectiveness. There is no one fits all solution and the biggest group living in the Baadu area are still pastoralists who should not be forgotten. Talking about the pastoralists one should not forget women who might be in need of different assistance than men. Without their incorporation any measure is foreseen to fail.

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7.5 Further Information

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8. Impact assessment of *Prosopis juliflora* invasion in the Afar Region, Ethiopia - Synthesis and recommendations from an interdisciplinary perspective

John Ilukor, University of Hohenheim, Germany
Simone Rettberg, University of Bonn, Germany
Anna Treydte, University of Hohenheim, Germany
Regina Birner, University of Hohenheim, Germany

8.1 Introduction

The following paper is the fruit of a multidisciplinary research work on the spread of *Prosopis juliflora* as an invasive species in the Ethiopian Afar Region and on options of its management and control. As one of the most invasive species of arid and semi-arid areas of the East-Africa *Prosopis juliflora* has also become a major threat to livelihoods of the Afar pastoral people and to the fragile ecosystems they live in. The research work provides recommendations for the development of effective development measures in the region. It has been carried out by three Ethio-German research teams led by the University of Hohenheim (ecology, economy) and the University of Bonn (sociology, remote sensing), coordinated by the GIZ sectoral project "Rural Development" and financed through the German Federal Ministry for Economic Cooperation and Development (BMZ). The full research reports can be found in the proceedings of the "Regional Conference on Managing *Prosopis juliflora*".

8.2 Background to the study and findings

The spread of invasive plant species within the arid and semiarid lowlands of North-east Ethiopia is an increasing threat for pastoral livelihoods and ecosystems. One of the most invasive species is *Prosopis juliflora*, an evergreen, fast-growing mimosa tree or shrub, native to South and Central America, which is considered in the National Biodiversity Strategy and Action Plan (MoARD 2005) as one of the top invasive species next to Parthenium weed (Parthenium hysterophorus), water hyacinth (Eichhornia crassipes) and Lantana weed (Lantana camara). In 2006, approximately 700,000 ha of land had been taken over by *Prosopis juliflora*, out of which more than 70% is located in the Afar Region, mainly within the Middle and Lower Awash Valley of the Afar National Regional State (ADMASU 2008, RYAN 2011) . Recent studies by AYANU et al. (2014) and HAREGEWEYN et al. (2013) have shown that the invasion rate is increasing rapidly, suppressing indigenous plants, while negatively affecting human health as well as livestock production. This species creates an environment that is conducive for mosquito breeding, limits access to watering points and grazing lands and offers cover for wild animals like lions.; Attempts to access these areas have resulted in injuries to both animals and humans (MWANGI & SWALLOW, 2008). The invasion of *Prosopis juliflora* also offers

positive impacts, for example, increased production of firewood, charcoal and wind breaking because it grows and coppices fast, has dense ground cover and is deeply rooted (Ayanu et al., 2014). In addition, *Prosopis juliflora* can play a significant role in rehabilitating degraded land and in restoration restoring salinized soils (BHOJVAID & TIMMER, 1998) However, the management measures that have been adopted in the Afar Region are not able to manage and control its rapid spread and it appears that the negative impacts exceed the positive impacts, especially for pastoralists, the main inhabitants of Afar Region in Ethiopia.

Against this background, the BMZ via the GIZ sectoral project "Rural Development" funded an interdisciplinary research study on 'Woody Encroachment in the Afar Region, Ethiopia: Impact Assessment of *Prosopis juliflora* Invasion and Participative Management Approaches'. In 2013/14, the study was implemented by Ethiopian-German research teams led by the University of Hohenheim (ecology, economy) and the University of Bonn (sociology, remote sensing) with the objective to assess the extent and impact of land degradation through *Prosopis juliflora* in the Afar Region, and to estimate the costs and benefits of *Prosopis juliflora* invasion. It was decided to focus on an empirical case study within one of the most heavily invaded areas in Afar, the Middle Awash Basin, the seasonally inundated floodplains of Gewane and of Amibara Woreda, where *Prosopis juliflora* has spread rapidly over the last decades (RETTBERG & MÜLLER-MAHN, 2012).

The quantitative assessment of *Prosopis juliflora* spread within the Baadu area (Gewane Woreda) based on a comparison of satellite images revealed that until end of 2013 almost 40 % of the wetland vegetation in Baadu had been taken over by *Prosopis juliflora* while the surrounding higher-lying dryland area has remained almost free of *Prosopis juliflora* so far (see proceedings Ayanu). Other highly invaded areas within Baadu included abandoned farms, roadsides and settlements. This discontinuity in the spread pattern of *Prosopis juliflora* implies that specific socio-ecological conditions favor its growth in areas of moist soil conditions that contain a large number of livestock, i.e., the floodplains along the Awash River. However, current spreading patterns show that *Prosopis juliflora* has the potential to also invade dryland areas distant from the Awash River (representing rainy season grazing lands). *Prosopis juliflora* has started to grow in key dryland grazing areas where the concentration of animals and the duration of grazing have increased due to the loss of floodplain grazing areas to *Prosopis juliflora*., This observation was supported by the results from ecological analysis which suggests that *Prosopis juliflora* infests areas that have been overgrazed and lack both a healthy woody and herbaceous layer component (see proceedings TREYDTE et al., 2008). This colonization trend is worrying because the Afar Region shows low plant species diversity as well as richness and the spread of *Prosopis juliflora* might reduce this diversity further. Nonetheless, the overall vegetation biomass was found to decline with a decreasing invasion rate of *Prosopis juliflora* according to the ecological study.

Due to the significant loss of the previously abundant grasslands in the floodplain areas, a key grazing resource for pastoralists during the dry season and drought times the pastoral vulnerability to drought has increased tremendously. Hence, the drought of 2003 left many of the pastoralists, especially those who depended on cattle, destitute. With the loss of indigenous grasses, the main fodder resource for grazers such as cattle, the number and productivity of animals has reduced substantially (proceedings Hamedou). Further, socio-economic impacts triggered by the invasion of *Prosopis juliflora* comprised increased health risks due to higher exposure to predators and malaria, constrained access to water points and the emergence of new fatal animal diseases like "Harmaku", resulting from cytotoxins damaging the neurons of the intoxicated animals (SILVA et al., 2007). Nevertheless, *Prosopis juliflora* is only one among several ecological problems. A ranking exercise within Kebeles affected by *Prosopis juliflora* revealed that Afar pastoralists perceived the diminishing water volume of the Awash River as problematic as the spread of *Prosopis juliflora* or even worse (see proceedings Hamedou).

Most pastoralists within Baadu, previously known for their wealth due to large cattle herds, now live under conditions of chronic food insecurity (RETTBERG 2010). Consequently, there has been a significant diversification of pastoralist livelihood strategies and engagement into non-pastoral economic activities. More and more pastoralists became sedentary within the last years, performing different kinds of income-generating activities (wage labour, petty trading, sale of charcoal, firewood, grass mats, etc.) and small-scale irrigation agriculture (RETTBERG & MÜLLER-MAHN, 2012; RETTBERG, 2010). Still, in most households there are some boys and men who keep on moving with the remaining livestock, while it is mostly women who take over new economic roles and engage in income generation, a severe additional work burden besides their socially assigned household chores (see proceedings Imkermann). It is, therefore, women who buffer the crisis of pastoralism. On one hand, this phenomenon is linked to an increased vulnerability of women; on the other hand, women, especially near urban areas, have started to become more conscious about their power and rights. Nevertheless, most pastoralists, men and women alike, perceive *Prosopis juliflora* as a 'curse from Allah' and opt for its complete eradication. The most common mitigation measure currently employed by the communities to control the spread of *Prosopis juliflora* is the clearance of the trees by cutting and burning, sometimes including uprooting, sometimes without.

Only few Afar people value *Prosopis juliflora* for its economic potential and consider it to be a 'black gold' due to its monetary benefits through charcoal production and trade (see proceedings Datona). With the invasion of *Prosopis juliflora* charcoal production has been booming within the flood plains of Baadu, linked to a massive influx of migrant workers from the highlands. Few, mainly young and educated, Afar have been able to generate high profits through charcoal trade but with severe ecological consequences due to the illegal cutting of indigenous trees, which is against the traditional law of the Afar (maada). This law is not respected anymore and the role of customary institutions in natural resource management is increasingly undermined (see proceedings Datona). There is also serious concern by some interviewed pastoralists that the few powerful people engaged in charcoal making are in favor of the spread of *Prosopis juliflora* and, hence, are acting against encroachment control efforts. The risk for resource based land conflicts within and among Afar clans and neighboring ethnic groups in the *Prosopis juliflora* affected areas is increasing with the commodification of land through charcoal trade and agriculture (see proceedings Hamedou). Therefore, most visited communities were not optimistic about the idea of controlling the spread of *Prosopis juliflora* through its utilization for fear of conflict of interest among some members of the communities who are benefiting, e.g. from charcoal trade. The communities believe the most effective way to control the *Prosopis juliflora* spread is its removal by uprooting and a continuous use of land reclaimed from *Prosopis juliflora* for development purposes such as irrigation based agriculture and/or rangeland development.

Results from economic analyses reveal that the benefits of the *Prosopis juliflora* invasion in the Afar Region are higher than the costs. Results also show that if the current invasion level is not controlled, the costs in next 30 years are enormous and will exceed the benefits (see proceedings Ilukor et al.). Moreover, the benefits and costs tend to vary with user groups such as mobile pastoralists, sedentary small scale agro-pastoralists, and large-scale farmers (Ayanu et al., 2014). In this study we find that the benefits to sedentary small scale agro-pastoralists who participate in wood and charcoal trade as well as those to large-scale crop farmers are higher than the costs. Nevertheless, if the current invasion rate is not controlled the benefits to these user groups would be less than the costs in the near future. In the case of pastoral livelihoods, the costs were found to be higher than the benefits and these costs are expected to escalate in the future if *Prosopis juliflora* is not controlled. For this reason, pastoralists prefer complete eradications and are willing to contribute cash as well as labor to reach this goal relative to non-pastoral households (see proceedings Mesfin et al.).

However, complete eradication will have significant impacts on the environment in form of increased wind erosion, evapotranspiration, and sun radiation. It further would reduce the ability of the Afar environment to sequester carbon. Analyses of existing data about *Prosopis juliflora* invasion generated from a study by HAREGEWEYN et al. (2013) and climate data acquired from the Amibara weather station reveal that the *Prosopis juliflora* invasion has been useful in moderating climate variables and reducing expansion of desertification in Afar Region (see proceedings Ilukor et al.). Also, results from ecological analysis reveal that *Prosopis juliflora* encroachment enhances the overall plant biomass and its Carbon stocks. Enhanced plant biomass above and below ground as well as higher organic matter content in soils can contribute to capturing CO_2 from the atmosphere, which is important for climate change mitigation (HASEN-YUSUF et al., 2013). It further can promote future Carbon trade efforts, which might provide an alternative income generation through payment for environmental services (PES). Moreover, as results from ecological analyses reveal, soil available phosphorus, nitrogen and carbon were found to be high in highly and intermediate *Prosopis juliflora* infested sites. Therefore, the soil properties in highly infested sites are suitable for plant growth or crop production once *Prosopis juliflora* has been removed.

Based on the results of this multi-disciplinary study, the feasible option seems is partial eradication of *Prosopis juliflora* followed by controlled land reclamation in certain areas and a controlled use of *Prosopis juliflora* wood, e.g. through charcoal production, in other areas as opposed to complete eradication. In particular, *Prosopis juliflora* should be eradicated in traditional grazing areas where native forage plants, both woody and grassy vegetation, can regrow. Ecological studies showed that the seed bank of native species in Amibara and Gewane is still intact beneath a dense *Prosopis juliflora* layer, which is an indication that there is potential to reclaim land once covered by *Prosopis juliflora*, even if the encroachment phase has been going on for several decades (see proceedings TREYDTE et al., 2008). In high potential crop lands, tall *Prosopis juliflora* trees that improve soil quality should be left to allow households to grow crops while the *Prosopis juliflora* trees should be used for shade purposes, charcoal or firewood. As results from the ecological analysis reveal, sites of high *Prosopis juliflora* encroachment did not show a high proportion of seedlings of this species, thus *Prosopis juliflora* is expected to become less abundant over time due to self-thinning and its allelopathic effects (TREYDTE et al., 2008).

Eradication and management of *Prosopis juliflora* will need to be conducted over a long time and be monitored permanently. Furthermore, the cleared area needs to be used immediately by planting of other plants, crops or forage to limit the invasion of *Prosopis juliflora*. In other words, there is need to physically remove *Prosopis juliflora* as well as to reseed native plants; the reclaimed land should either be used for pasture or crop farming. As shown by the results in the conference proceedings, mechanical control is perceived by households as the most preferred and cost-effective method. In the Afar Region there are two alternative mechanical methods used for clearing *Prosopis juliflora*: clearing of stems with and without digging out the roots. Digging out roots is said to be environmentally effective as it prevents *Prosopis juliflora* from re-sprouting and coppicing. Results from the cost benefit analysis show, however, that digging out roots is cost effective only if the reclaimed land is used for either crop production or pasture management and if the wood is used for cooking, is being sold or used for charcoal burning. However, dependence on rain-fed agriculture and the inadequate number of electric generators for irrigation purposes limits the households from utilizing reclaimed land for crop farming. Additionally, weak land user rights do not encourage the participation of households in land clearing. Households noted incidences when they cleared *Prosopis juliflora* off the grazing land only for the government to offer the same land to an investor, since this land belonged to government. Worse still, the mode employed to clear *Prosopis juliflora* (communal clearing, at which soldiers, police, and community members are involved) limits the participation of migrating pastoral households.

8.3 Recommendations

Based on the results of the joint impact assessment a vision about the way forward emerged that points towards the need for a participative, institutionalized, locally-owned and government-led management approach. In this context, the following recommendations for the sustainable management and control of *Prosopis juliflora* in the Afar Region are made:

Securing sustainable reclamation of land

As the study came to the conclusion that a total sustainable eradication of *Prosopis juliflora* is impossible, there is an urgent need to promote a) clearing of *Prosopis juliflora* in some selected areas with use of the wood for either charcoal or fuel wood and b) immediate utilization of the cleared land for either pasture or crop farming. Implementation of this recommendation will require creating innovative ways of involving pastoralists in mechanical clearing of *Prosopis juliflora* by tapping into local knowledge, local institutions, and providing land use rights of the cleared land as well as suitable tools for farming, especially generators for irrigation. Pastoral clans, institutions, and locations should be mapped and documented. Each clan should be empowered to oversee the clearing of *Prosopis juliflora*. The clans should be supported and community rules should be developed, providing financial and technical support on how the land can be continuously kept free from *Prosopis juliflora*. This support should essentially come from the government and even development partners. In addition, the same clans should also be offered the right of use, of income from the *Prosopis juliflora* wood and the rights to use land for crop or forage production.

Building of a multi-level institutional set up

For any management approach to become effective on the ground there has to be a strong institutional structure with clear mandates and responsibilities. First of all, it is necessary that the current contradictory policies be replaced by coherent mainstreamed policy giving a clear direction to all parties involved. Furthermore, it is recommended that one organization on the federal level (preferably the Ministry of Agriculture) should be given the mandate as a lead organization of the *Prosopis juliflora* eradication (proceedings Chekol). Under the lead organization further institutions should be developed at all administrative levels. All these governmental institutions need transparent mandates and sufficient budgets for *Prosopis juliflora* management. Local institutions at regional and Woreda level should be linked to customary institutions of natural resource management, e.g. through the establishment of joint boards or management committees.

Strengthening local institutions through participation and ownership

Both local and national level institutions and institutional arrangements are needed to ensure sustainable management of *Prosopis juliflora*. However, greater focus would be in the local institutions which should be linked directly to the existing government institutions and institutional arrangements. The local *Prosopis juliflora* management institutions should be developed in line with the existing local institutions on pasture management. In Afar there are customary leaders called makabantu that are involved in decision making in matters related to clan grazing lands, relationships with other clans, neighbours and the state; the fiimat abba who enforce decisions made by the makabantu of individual clans and the clan leaders from the associated grazing lands (ulooto) (See OBA, 2012). These existing local institutions should be activated and involved in the management of *Prosopis juliflora*, and this would require documenting existing "clans" and an examination of their community rules before adapting them to the management of *Prosopis juliflora*. In addition, this process would ensure that *Prosopis juliflora* management institutions are developed participatively by involving communities and their leaders. Participatively developed institutions that are locally owned are the key to sustainable management and control of *Prosopis juliflora* in the

Afar Region. They will ensure that pastoralist knowledge and views form the basis for control and management of *Prosopis juliflora*, thus, minimizing the tendency of forcing interventions to them. It also minimizes the "free rider problem" the tendency of some pastoralists or households not to participate in *Prosopis juliflora* clearing or management but benefit from the clearing by others. By providing social sanctions and incentives, pastoralists themselves who are strongly affected by *Prosopis juliflora* invasion would be more actively involved in its management and control other than armed forces that have no incentives. Group based sanctions or incentives such clan sanctions or multi-clan sanctions would even be more effective (REUBEN, 2003).

Therefore, customary institutions and authorities of local Afar communities have to be revitalized and have to become legally recognized to voice their interests and needs. They are vital for finding a culturally appropriate entry point for communication with the communities and to create a relationship of mutual trust between external development organizations/ individuals (e.g. Ethiopian Highlanders, Foreigners) and clan members. One main task will be to organize pastoralists in associations or cooperatives and to equip them with basic literacy and management skills to develop their own agenda. Pastoral associations on clan level would serve as executing bodies, but also as channels for dialogue on development priorities, for co-learning, sharing of ideas and partnership with external actors. Up to now, more than 90% of the population in rural Kebeles (villages) is illiterate. In order to ensure the participation of local communities in planning/designing as well as implementation of *Prosopis juliflora* management interventions education/training will be a major issue. It will be highly important to support and involve women in any management activities since they are the main innovators in terms of taking up new economic activities; further, women tend to deal in more responsible way with financial resources than men. Nevertheless, they are already now overburdened with their workload, which might pose a serious constraint.

Focusing on specific *Prosopis juliflora* invaded areas

Ecologically, some areas are better suited for a *Prosopis juliflora* - eradication than others. E.g., areas with high and dense *Prosopis juliflora* cover might be too difficult and labor / finance consuming. These areas are likely to decline in *Prosopis juliflora* in the future, anyway, due to self-thinning effects. In contrast, areas that have been invaded rather recently should be cleared selectively and intensely (including root removal). The latter areas are less densely populated with *Prosopis juliflora* and might show the positive effects of this species onto the soil layer as found in the ecological study. These positive soil characteristics can be used for consecutive planting of native species or cropping fields.

The cleared areas should immediately be restocked with native woody and grassy vegetation to prevent new invasions as abandoned and unused areas are preferred colonization grounds for *Prosopis juliflora*. Hence, an intact grass layer or a cropping field, e.g. a dense maize field, will prevent *Prosopis juliflora* from sprouting.

Further, the remaining grazing areas should be managed such that no overgrazing effects arise as the latter will encourage *Prosopis juliflora* invasions. The grass layer must be kept intact, and should be interspersed with few native trees but *Prosopis juliflora* growing into tree shape can also be allowed.

The spread of *Prosopis juliflora* must be undermined. This spread is mainly caused by pods being eaten by livestock or being transported in waterways or along roads. Hence, pods should be regularly collected and crushed before livestock can forage on these plant parts. Alternatively, livestock feces could be collected in the course of a day and used as fuel for fires, once dried, or as manure for crop fields in the near surroundings, after *Prosopis juliflora* pods have been removed.

Flexibility of management interventions

Management interventions should be a) context-specific, b) culturally sensitive and c) integrated. The current developments in Afar towards an increasing livelihood diversification within and between households and clans and the value of the co-existence of mobile pastoralism and settled agro-pastoralism through risk-spreading and complementary land-use calls out for context specific and integrated strategies depending on the spatial and social context. There is no one-fit-all-solution. Instead, interventions should support the complementarity of mobile pastoralism and agro-pastoralism and respect the culture and indigenous law of Afar (maada) in natural resource management. Clans currently affected by the *Prosopis juliflora* invasion in proximity to the Awash River combine different livelihood strategies, including mobile pastoralism, settled small-scale agriculture and charcoal production. The reclamation and future use of land has to take note of this diversity, which should be supported. In addition, there is need to improve the provision of animal and human health care services in the Afar Region. Although *Prosopis juliflora* is associated with the emergence of new animal diseases like Harmaku and increased incidence in malaria, there is no clear treatment for *Prosopis juliflora* related animal diseases. Most often the animals that fall sick are slaughtered, and those that die are disposed-off or left to rot in the bush since traditionally Afar pastoralists do not eat the meat of animal found dead. In the case of Malaria, there are few, crowded and distant health units without hospital beds available for pastoralists. Investment in health care and provision of veterinary services as well as extension services for animal production should be boasted to address the emerging impacts of *Prosopis juliflora*.

Strengthening regional cooperation and learning

In addition to local and national institutions, there is a need for regional policies and institutions to facilitate efforts to control and manage the negative impacts of *Prosopis juliflora* and optimize the positive impacts of this species through sharing knowledge, advocacy and research. The establishment of the regional institutions and policies should be spearheaded by Intergovernmental Authority on Development (IGAD).

Encouraging further research

There is a need to invest in *Prosopis juliflora* research in Afar in order to develop innovative ways of controlling this species but also assessing and appreciating the impact of *Prosopis juliflora* invasion in the Afar Region of Ethiopia. Particular areas of research that need to be addressed are

- the feasibility of biological control, agents using experiences from other countries,
- the relationship between spreading patterns and hydrological conditions,
- the role of *Prosopis juliflora* in desalinization and crop production and
- an in-depth institutional analysis should be implemented to highlight why the existing *Prosopis juliflora* management strategy for Ethiopia has not been implemented so far and what institutional arrangements will work for *Prosopis juliflora* management in Afar.

Research on innovative uses of *Prosopis juliflora* that are socially acceptable and suited to the Afar Region and people, for example, on the possible use of *Prosopis juliflora* pods as source of human nutritious foods, medicinal uses and as the basis of livelihood diversification, based on the experience from other countries, should be done. The research should be participative, and research results should be disseminated not just to scientists alone but also to local people. This would be useful in creating awareness of the uses of *Prosopis juliflora* for the communities and diversification of livelihood in the long run. The study results revealed, Afar households have limited knowledge on uses of *Prosopis juliflora*, yet other communities in Kenya, South America consider this species as a gold mine. Moreover, it is also important to examine if a lack of awareness is the only factor that prevents local pastoralists from using *Prosopis juliflora* or control-

ling the spread of its seedlings. Other factors like tenure insecurity, poverty etc. may influence local decisions. Social research should value local knowledge not only as deficit but as different from external/expert knowledge and try to learn from local people in order to understand their decisions and actions. Investment in research in the above topics is not only important in estimating a fairly accurate impact of *Prosopis juliflora* among Afar households but also is creating pathways for livelihood diversification among Afar pastoralists, which is increasingly threatened by climate change and climate shocks.

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9. Controlling and/or using *Prosopis juliflora* in Spate Irrigation Systems

Matthijs Kool, MetaMeta, Netherlands
Karim Nawaz, Spate Irrigation Network, Pakistan
Yasir A. Mohamed, UNESCO-IHE, Netherlands
Hamis Nzumira, UNESCO-IHE, Netherlands

9.1 Introduction

This paper describes one of the most invasive shrubs in spate irrigation systems, i.e. *Prosopis juliflora* also known as mesquite. The paper focuses on how it disturbs the management of spate irrigation systems and crop cultivation in Eritrea, Ethiopia, Pakistan, Sudan and Yemen. It gives country overviews of when and for what purpose *Prosopis juliflora* was introduced and the programs that have taken place to eradicate or manage the plant (chapter 2). Further the different mechanical, chemical and biological eradication methods are mentioned (chapter 3) and how *Prosopis juliflora* can be used as a valuable resource for purposes such as charcoal or timber (chapter 4). From this, it aims to take stock of the problems and draws some tentative lessons on how to control or use the shrub.

Prosopis juliflora invades land and even worse encroaches on river beds and canal beds – blocking them and causing drainage patterns to uncontrollably shift. Yet *Prosopis juliflora* is a blessing as well, albeit mixed. It is a source of biomass in some of the most marginal lands and provides fuel wood, charcoal and fodder.

This paper makes an assessment of how to manage this 'mixed blessing' in spate irrigation systems, based on first-hand experience and grey literature. In the last thirty years the hardy well rooted shrub made its way from Latin America to all parts of the world, covering millions of hectares in for instance India, Pakistan, Yemen, Sudan, Somalia or Ethiopia. In many places it was first introduced in sand dune stabilization projects. However *Prosopis juliflora* has the habit to 'overstay its welcome' and expand rapidly and not go away. The area estimated conquered by the invasive species in the last ten years in India. Pakistan, Yemen, Kenya, Sudan and Ethiopia is way above 10 million hectares. Particularly in areas where there is livestock grazing *Prosopis juliflora* spreads rapidly: the seedpods cling to the animal skins and are distributed widely. *Prosopis juliflora* germinates easily and once it has settled in an area it is difficult to get rid of it. It takes over the natural vegetation, does not allow undergrowth and hence greatly reduces the grazing value of land.

It also tends to creep into waterways – including dry riverbeds – choking them in the process and causing flooded rivers to run wild. The *Prosopis juliflora* thorns are poisonous and can even cause blindness. Livestock, particularly cattle, can become ill when they are almost exclusively fed with pods of *Prosopis juliflora*. Symptoms can be facial contortions and constipation, sometimes resulting in death. In the Tihama region in Yemen, farmers consistently ranked *Prosopis juliflora* in the top three of major problems.

Prosopis juliflora is not only a scourge. It also has benefits to its credit. It is important for people in provid-

ing fuel and timber. The sweet nutritious pods are eaten by all livestock and can be made into different foods and drinks. Honey is made from the flowers and the gum is similar to gum arabic. The bark and roots are rich in tannin and the leaves can be used as mulch or to help in reducing pests and weeds. Also as a nitrogen fixing tree it improves the land and can reclaim saline soils. Furthermore in India charcoal generated from biomass of *Prosopis juliflora* improved the fertility of alkaline soils (SAI BHASKAR REDDY, 2009). On balance however if unmanaged it is a scourge that is steadily undermining the livelihoods of large populations in some of the most vulnerable dry agricultural and pastoralist areas.

9.2 Countries overview

Eritrea

Prosopis juliflora in Eritrea is widely known locally as Temer, Musa or Sesban. *Prosopis juliflora* entered into western and northern Eritrea from the Sudan, probably during the early 80s, and was introduced by livestock (BOKREZION, 2008). *Prosopis juliflora* can be found in both the Western and the Eastern Lowlands irrigated areas. Because of the relative high water availability in irrigated areas, *Prosopis juliflora* is in these areas flourishing. It obstructs the diversion channels and invades irrigated crop land. Because farmers have to remove seedlings and shrubs from the fields and clear the diversion channels, cultivation becomes more labour intensive and costly. *Prosopis juliflora* is especially a problem in Gash Barka where irrigation takes place to a large extent. Although *Prosopis juliflora* is used as a source for fire wood and fodder, *Prosopis juliflora* has also a great impact on native grassland and range land species. The level of infestation in Eritrea still remains relatively low, but it can potentially become a serious risk over the long-term on farmers' food security (BOKREZION, 2008).

Ethiopia

Prosopis juliflora was widely distributed in Ethiopia as a biological soil and water conservation agent during the late 70s. Now it is considered a major threat because of its invasive nature. *Prosopis juliflora* has an aggressive invasive character invading pastureland, irrigated cultivated lands and irrigation canals causing an irreversible displacement of natural pasture grasses as well as native tree species (Kassahun et al., 2004).

In terms of coverage, the areas most adversely affected nationally include the Afar and Somali Regions in the east and southeast of the country and the area around Dire Dawa City. There are also moderately affected areas in Amhara, Oromia, Southern Nations Nationalities and Peoples (SNNP) and Tigray Regions – that is, in the mainly dry lands of Central, East and North Ethiopia (Steele et al., 2009).

Infestations typically originate from the many small villages, extending along the main routes and are now steadily advancing into the surrounding landscape. The invasion of *Prosopis juliflora* corresponds with movement of animals being driven to markets and nomadic settlements. It has also spread to cultivation areas and flood plains along the river Awash, which is of high economic importance to the region (Senayit et al., 2004). Many communities and farmers have belatedly attempted to eradicate the plant.

However, *Prosopis juliflora* particularly when it is cut above ground, it simply regenerates and it has almost become impossible to get rid of it. Especially in the Afar Region, where the invasion of *Prosopis juliflora* is most severe, much effort has been done to manage and control the shrub. In Afar Region the production of charcoal from *Prosopis juliflora* was very much encouraged. The problem however was that the *Prosopis juliflora* charcoal was inferior to the one from acacia for instance. Instead of *Prosopis juliflora* charcoal the acacia was widely processed – accelerating the degradation of the common land. A total ban on charcoal

trading was hence reinvaded in several parts of this region.

Furthermore the NGO Farm Africa has tried on controlling *Prosopis juliflora* in the Afar Region in a number of ways: First to uproot the plants and then very rapidly convert the area into an agricultural area or into a well-managed grazing area – so as not to allow a comeback. Secondly to encourage the regulated production of charcoal through a number of co-operatives. Thirdly to systematically collect the pods and crush them into animal feed – making sure they do not germinate but are turned into an economic asset (Tegegn, 2008). Results from a pilot initiative showed that there was a potential to control the spread of *Prosopis juliflora* by promoting utilization. However the pilot initiative was not supported with realistic land use plans. Due to this, cleared pasture lands were re-invaded from the seeds in the soil or new seed load from animals or flood (Tegegn, 2008).

Pakistan

Prosopis juliflora is locally known in Pakistan as Babul, Valiati Kikar, Kabuli Kikar. In the second half of 19th century, it was brought to Pakistan from Mexico and introduced into the semi-arid areas of the country. Sindh province was among the initial sites where it was first introduced. The main purpose was to control soil erosion and desertification. Its propagation was encouraged in places like Balochistan where no other vegetation could easily grown. Much later it became a weed and aggressive plant in many irrigated and valuable land tracts. It is now encroaching aggressively on rangelands and suppressing natural vegetation and dominating fallow lands. Spate irrigation areas in DG Khan are facing *Prosopis juliflora* problems in its command areas. Once it established, it was very difficult to eradicate as its roots penetrated deeply. Some experiments show that roots have penetrated to a depth of more than 50 meters. Due to *Prosopis juliflora*, farmers have difficulties to manage the water at channel and field level during floods.

Prosopis juliflora growing in water channels and passages slows down or even block the spate flow. Further the thorny bushes of *Prosopis juliflora* causes serious problems for barefooted farmers to work properly and it obstructs livestock from accessing drinking water. The invasion by *Prosopis juliflor*a also suppresses the indigenous vegetation such as tamarisk and some species of acacia that are used to divert water from channels to the fields and to block the inlets after irrigation. Farmers complain that this causes a shortage of useful and easily handled plants that are used to divert water from channels to fields and also for blocking the inlets after irrigation. Farmers can only control the invasion of *Prosopis juliflora* with strenuous effort using methods such as uprooting, cutting and burning with no guarantee of its complete control. In many cases these methods are costly, time consuming and beyond the capacity of poor people.

Although *Prosopis juliflora* has more negative aspects than positive, people found its benefits as well. Selling *Prosopis juliflora* as fuelwood or as charcoal is now a popular business for the Afghan Panwandas in DG Khan, DI Khan and Barkhan and Loralai districts. They cut the *Prosopis juliflora* at large scale and sell its woods locally in their temporarily dwellings or as charcoal to hotels for 1000 Rs per bag (50kg). *Prosopis juliflora* is used in the brick kilns industry. Poor families sell cutted wood of *Prosopis juliflora* for 80 Rs per 40 kg to local brick makers. *Prosopis juliflora* attracts honey bees and honey farms can been seen around dense plantations. Further farmers use the branches of *Prosopis juliflora* for fencing fields against encroachment by livestock and wild animals. In some cases it is also used for boundary hedges around houses in rural areas especially in desert areas of Sindh, Balochistan and Punjab.

Moreover some research has been done in Pakistan how to cultivate *Prosopis juliflora* in saline areas for providing fodder, fuel wood and timber. For instance man made forests of *Prosopis juliflora* have successfully been established in the coastal areas of Balochistan by irrigating it with highly saline underground water (Khan et al., 1986). Ahmad (1994) carried out experiments to screen local and exotic *Prosopis juliflora*

species at germination and seedling stages under salinity conditions. Further *Prosopis juliflora* is used along the coast of Balochistan for sand dune control and prevention of sea incursion.

Sudan

Prosopis juliflora is known in Sudan since early nineteenth century (around 1917) when it was introduced in Khartoum for research purposes. The success of the tree in its abilities to tolerate drought and fix sand dunes was the reason to introduce the tree in more drought-prone areas. In the 90s, *Prosopis juliflora* was introduced as part of dune stabilization programmes in the spate irrigation systems of the Gash and Tokar.

However soon after its introduction *Prosopis juliflora* became a major pest. Tens of thousands of hectares were invaded in these areas. Figure 1 shows the land cover change of the Gash delta from 1979 to 2013. It shows that the area covered with *Prosopis juliflora* increased from 89,428 hectare in 1979 (24 % of a total area of 371,870 hectare) to 141,942 hectare in 2013 (38 %). The agricultural area however decreased in the same time from 32,125 (8.6%) to 23,538 hectares (6.3%). This area was mainly taken over by *Prosopis juliflora*.

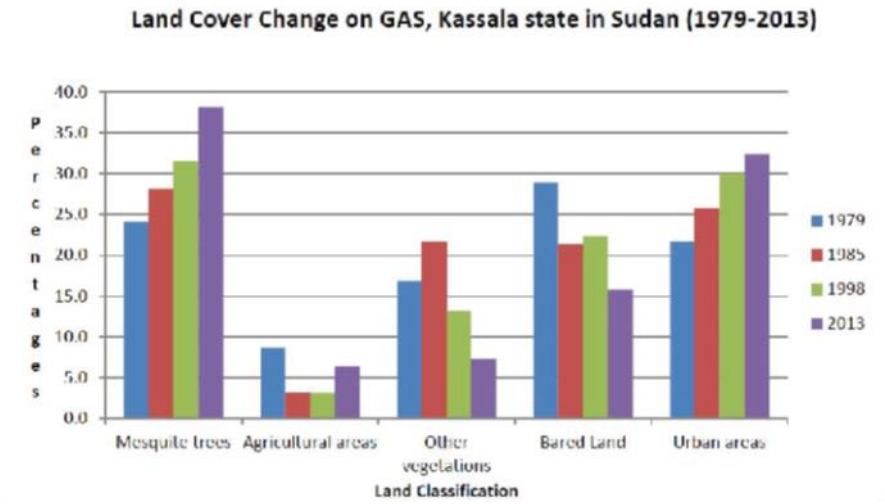

Figure 1: Land cover change in Gash spate irrigated areas (1979-2013)

Furthermore *Prosopis juliflora* had a negative effect on the cannel discharge capacity in the Gash delta. A decrease in the cannel discharge capacity lead to less crop production than expected by the farmers. Table 1 shows the effect of *Prosopis juliflora* infestation on the canal discharge capacity and (indirectly) on crop production.

The aggressive spread of the *Prosopis juliflora* in the Gash and Tokar spate systems was mainly the result of poor field and land management. This was related to the absence of permanent land ownership in these systems (VAN STEENBERGEN et al., 2010).

In the last 15 years, different programs and projects were initiated to eradicate *Prosopis juliflora* in the Gash and Tokar area. In 1996, the Kassala state government launched an awareness campaign to eradicate *Prosopis juliflora*. They mobilized local communities and school students to participate. During the rainy season, people had to collect seeds and pods and destroy them. Under the Gash Livelihoods Project (IFAD, 2004), land was titled to farmers on the condition that it would be taken back if they could not control the emergence of the shrub.

In 2005, the Kassala state government made contracts with private companies to eradicate *Prosopis juliflora*

from 150,000 feddans (6,300 hectares) in the Gash area. The cost of clearing *Prosopis juliflora* by using mechanical removal was 350 Sudanese pounds (50 dollars) per feddan (0.42 hectare). The costs for manual removal of *Prosopis juliflora* was 150 Sudanese pounds (21 dollars) per feddan.

Intake Canal	**Canal discharge capacity of canal designs (m^3/s)**	**Canal discharge capacity after infestation of mesquite trees (m^3/s)**	**Crop production*** **year**	**Crop production (bags)****	
				Harvest (bags)	**Expected production (bags)**
Fola	10	7.5	2006	16	22
Salamaleka	30	22.5	2007	20	27
Makati	20	15	2008	24	32
Digeni	58	23.5	2009	30	41
Tendalal	20	15	2010	13	13
Matatelp	20	15	2011	10	14
Hadalia	20	15	2012	14	15
Kassala	Not measured very small canal size		2013	Not harvested	

Table 1: The effect of *Prosopis juliflora* infestation on canal discharge capacity in the Gash scheme.
*Crop-Sorghum
**1 bag = 100 kg

Furthermore chemical and biological methods were used in which trees of *Prosopis juliflora* were cut one feet above the ground and then sprayed with diesel oil, 2-4 D chemicals, round up or clinic graivosade.

Although the farmers and companies did their task in a proper way, after one year the *Prosopis juliflora* was re-infested. Lack of follow up programs, inadequate management and weak enforcement of regulations played a major role in re-infestation of *Prosopis juliflora* in the Gash area. However an example that with proper management and regulations *Prosopis juliflora* can be controlled is shown in Box 2 about the New Halfa scheme (Northern Sudan).

In the Tokar delta, a Food for Work program was run to control *Prosopis juliflora*. Families of low income were mobilized to the delta, by offered food and two hectares of *Prosopis juliflora* infested land. *Prosopis juliflora* pods were swapped for sorghum to encourage collection. Although *Prosopis juliflora* has very big disadvantages, the shrub has also its benefits and farmers in Gash and Tokar use *Prosopis juliflora* as a source of fodder and river bank stabilization. The poor and landless are able to generate income from charcoal making and fuel wood from *Prosopis juliflora* and forest depletion has been reversed with the spread of the shrub. Given the areas that are covered with *Prosopis juliflora*, one can say that it has become the second most important crop in the Gash area after sorghum (IFAD, 2011).

However there are sharp debates in Sudan whether to get rid of *Prosopis juliflora* or to adapt into the ecological system of the areas concerned.

Box: The New Halfa scheme, Sudan.
In 2008, in the New Halfa scheme (Northern Sudan), a company was hired by the government to control the invasion of *Prosopis juliflora*. The total irrigated area of 330,000 feddans (138,600 hectares) was for more than two-third affected with *Prosopis juliflora*. By using heavy machines, it took the company 2 years (from 2008 to 2010) to clear the area for 98%. After the program, the land was titled to registered farmers under the condition that they were not allowed to take animals onto the agricultural fields even after the growing seasons. Regulations and by-laws enforced that the area was not re-invaded by *Prosopis juliflora*.

Yemen

In 1974, *Proposis juliflora* was introduced into Yemen by the Tihama Development Authority to combat soil erosion (GEESING et al., 2004). Due to the very recent detection of the invasion, only limited statistical information is available that underestimate to define the importance of the problem. In wadi Hajar, the whole wadi system and its associated sandy fringes have been stabilized by the planting of the introduced shrub *Prosopis juliflora*. However *Prosopis juliflora* is such a major problem that villagers said the shrub was responsible for exacerbating the 2008 floods by blocking watercourses and diverting floodwater into villages. The same is reported from the Hadramawt.

Areas in the Hodeidah Governorate, Hadramout Lahej, Abyan and Shabwa are at risk in terms of food security problems if additional agricultural land is invaded by the species. In the Abyan and Shabwa Governorates the invasion is very recent and severe and, although *Prosopis juliflora* was successfully introduced to combat soil erosion, its recent uncontrolled spread is cause for major concern by farmers, who are confronted with harsh climatic and soil conditions and have very limited irrigated land for agricultural production (FAO, miscellaneous).

A particular problem for spate irrigation areas is the establishment of *Prosopis juliflora* in the irrigation systems where they disturb the water flow. One most important drawback being mentioned by beneficiaries of spate irrigation systems was the encroachment of river beds and canals with *Prosopis juliflora*, blocking the water flow when it occurs (METAMETA, 2012).

In the 90s, a growing number of voices were raised against *Prosopis juliflora* invasion of farmland. Complaints came in particular from large landowners growing irrigated cash crops (cotton, onions, watermelons, wheat and various vegetables), even though the offending species had often been planted by the farmers themselves (GEESING et al., 2004). *Prosopis juliflora* has invaded areas of orchards and sorghum fields, where farmers currently hand pull new shoots of the plants (ALI et al., 2006).

For instance in Al-Mujaylis, in Tihama coast plain, date palm orchards were invaded by *Prosopis juliflora*. Most of the palm trees died, because *Prosopis juliflora* essentially sucked up all the moisture away. *Prosopis juliflora* can be invasive but exploiting the resources for fuel wood, fodder and food can counterbalance the damage. At the request of the Yemen government, in 2002/2003 FAO implemented a project to manage and control *Prosopis juliflora* better. Farmers were trained in the use of *Prosopis juliflora* pods for animal feeding and the stems of the plant for firewood. Recently the collection of *Prosopis juliflora* pods became a profitable enterprise for local people, who collect them in the plains and transport them to feed animals in higher altitudes (GEESING et al., 2004).

9.3 Control or management

Many efforts have been done to eradicate and control *Prosopis juliflora* from its areas of invasion.

GEESING et al. (2004) categorized the eradication methods into three broad types:

- Mechanical; plants are removed by machine or people mechanically by hand pulling, cutting, hand digging or mechanical uprooting. This is severely done in Gash, Sudan and Afar, Ethiopia but it didn't give the expected result, due to lack of maintenance. In Australia several mechanical methods have been used. This is stick racking (best results are achieved when soil moisture is sufficient to allow machinery to work with minimum strain, but soil is dry enough so the root system desiccates), chain pulling (may kill up to 90% of trees in a mesquite infestation. However, the effectiveness of control may be reduced when either very dense infestations or a high proportion of young trees and seedlings are present) bulldozer pushing and blade ploughing.
- Chemical; Larger trees and shrubs are killed by cutting the stem at ground level and spraying or painting the freshly cut stumps with suitable herbicide. Herbicides like Round up, 2-4, D, Glenside Kerosene and diesel oil are used. Table 2 shows examples of herbicides that are registered and used for the control of mesquite in Queensland, Australia.
- Biological; predators or pathogens are used to control the *Prosopis juliflora* reproduction. Sudanese researchers found some predator insects that attack the leaves that lead to deterioration of the tree canopy. In Australia four species of insects have been introduced as biological control agents against mesquite: The Algarobius bottimeri and Algarobius *Prosopis juliflora* (The larvae of these beetles destroy mesquite seeds in mature pods both in the trees and on the ground), the Prosopidopsylla flava (a sap-sucking psyllid that causes dieback) and Evippe spp. (a leaf-tying moth that causes defoliation). Nevertheless, this is a very slow operation to eradicate the tree (DAFF Queensland, 2013).

Situation	**Herbicide**	**Rate**	**Optimum stage and time**	**Comments**
Basal bark	triclopyr + picloram Access®	1 L/60 L diesel	Plant must be actively growing	For plants up to five cm in diameter. Wet stem thoroughly from ground to 30 cm height.
Cut stump	triclopyr + picloram Access®	1 L/60 L diesel	Plant must be actively growing	Stem should be cut close to ground level and treated immediately.
High volume (overall spray)	triclopyr + picloram e.g. Grazon DS Extra®	Refer to herbicide label	Plant must be actively growing	For seedlings and plants up to 1.5 m tall. Do not spray plants bearing pods.

Table 2: Herbicides registered for the control of mesquite, Queensland, Australia (Source: DAFF Queensland, 2013)

Another method that has been used in several countries is burning the stump after it has been cut. In Yemen for example the application of kerosene over the stump followed by burning has shown to be a way of eradicating the plant. However this only works when the plant is dry (not in stage of flowering) and the root system is not too deep to survive. Otherwise regrowth will occur. In general, experiences from America, Asia and Australia have shown that eradication of *Prosopis juliflora*, by the different methods, especially

the mechanical and chemical ones are highly expensive and mostly ineffective (HDRA, 2005). The magnitude of resilience and distribution of the plant makes *Prosopis juliflora* virtually impossible to eradicate once established. Eradication is also difficult, because a significant number of local people are depending on *Prosopis juliflora* for different purposes.

Furthermore because of its invasive nature, it asks a lot of maintenance keeping the land clean from *Prosopis juliflora* sprouts. Without any clear policies, organisation and regulations maintenance it will not happen. In Ethiopia for instance, although the stumps were cleared and seedlings uprooted to rehabilitate the land, due to lack of land use right, people were not allowed to manage and use the land and *Prosopis juliflora* re-invaded (TEGEGN, 2008).

Because most of the conventional control methods are expensive, it could be argued that the utilization of *Prosopis juliflora* is the best option to control the invasion for many invaded areas (TESSEMA, 2012). Many farmers and artisans, as well as researchers, argue that the tree is a valuable resource (HDRA, 2005). Exploring beneficial uses of the tree will help to turn it into a more useful tree and perhaps even, to some extent, curb its expansive growth. Thus more ecosystem services can be derived from *Prosopis juliflora*, though its disservice to biodiversity remains a reason for caution. An overview of the positive and negative aspects of *Prosopis juliflora* is shown in table 3.

Positive aspects	**Negative aspects**
Can play a role in sustaining the livelihood of poor rural households	Lack of traditional knowledge on how to manage and control the plants
Source of fuel and dry season animal feed	Obstructs paths and roads
Wood does not spit, spark of smoke excessively	Hard and costly to remove
Often in the commonly owned areas where they are freely available to the whole community	Expands quickly even in the harshest conditions
High quality and hard timber	Thorns can injure animals and people
Good animal feed especially for dairy cows	Depletes the water moisture and limits availability to local plants
Wood can be processed into furniture or construction material	Few plants are able to grow under its crown shade
Can act as vegetative fencing to delimit and protect properties	Can favour the breeding of malaria spreading mosquitoes
Produces good charcoal	Causes pastoralist communal lands to shrink

Table 3: Positive and negative aspects of *Prosopis juliflora*

9.4 Making use of *Prosopis juliflora*

Converting *Prosopis juliflora* into a valuable resource presents an opportunity to the communities living in marginal areas (PASIECZNIK, 2007). However to manage, control and utilize *Prosopis juliflora* full participation of local communities is necessary. Also appropriate control measures and follow up management

activities need to be done. Furthermore, strategic development and encouragement of the private sector to establish a market for *Prosopis juliflora* products is important. Marketing policies and interventions from government could help in this. Finally research have to be done about constraints in the harvest, processing and marketing of *Prosopis juliflora* products and success stories have to be documented.

Fuel and charcoal production

Prosopis juliflora wood is hard, burns slowly and has good heating properties. Also, the charcoal it can produce has good properties and can be easily traded on urban markets- although less popular than acacia. In Ethiopia farmers were trained in labour efficient charcoal production techniques using metal kilns instead of traditional kilns (ADMASU, 2008).

Box: Making charcoal
Approximately three to six kg of wood of *Prosopis juliflora* is required to produce one kg of charcoal depending on the method used. Charcoal is manufactured in traditional or improved earth kilns, or less commonly in metal kilns. Before processing, wood is first sorted into similar diameters and lengths. Earth kilns can be made up on flat ground, but charcoal manufacturers use large pits, on sloping ground. Wood is stacked and moistened before firing. The stack is covered with soil and burns very slowly for several days depending on the size and condition of the stack and site. The moisture content of the wood is reduced from approximately 45% to close to zero. After two to eight days, the stack is opened and the coals are removed, allowed to cool, graded and bagged up for use or for sale. (PASIECZNIK, 2001).

Timber

Prosopis juliflora wood is extremely hard and durable. It also has an appealing coloration that makes it ideal to make furniture with. The wood matures quickly and stems become dark inside when the plant is trained as a tree. The mature timber is resistant to pest attack and weathering and thus can be used for furniture making and other useful purposes especially housing. It is also used as parquet flooring wood. However particularly in stressful conditions of dry areas, *Prosopis juliflora* trees remain craggy, crooked and small, which makes using them to make furniture or charcoal less attractive.

Wood chips

Wooden residues from *Prosopis juliflora* can be chipped off and used as mulch in gardens and little vegetable gardens (Pasiecznik, 2001). The mulch is effective in reducing evapotranspiration. Consequently, it also reduces the plant water consumption. The chips have also been successfully proceeded into wooden pulp, which is the primary raw material for paper production (Pasiecznik, 2001).

Fodder

Free ranging animals can eat *Prosopis juliflora* pods directly from the tree. Alternatively, the pods can be collected and ground to produce course flour which can be included in the animals' diet. The percentage of the flour in the mix should be kept below 50% in order to avoid digestion disorders among the livestock (Pasiecznik, 2001).

Land reclamation

By spreading charcoal and using it as bio-char, acidic degraded land can be rehabilitated and yields can be increased. Charcoal improves the physical, biological and chemical properties of the soil by releasing and storing nutrients, increasing the bulk density, improving the overall porosity and creating favourable con-

ditions for micro-biological activity. It can be applied in conjunction with farmyard manure and/or soil microbes (Sai Bhaskar Reddy, 2009).

Bio-fuel

Prosopis juliflora is an underestimated source of sugars that can be converted into ethanol. Trials in the USA have shown that up to 80% of the pods carbohydrates can be converted in the process (Pasiecznik, 2001). This process, however, is still in an experimental stage.

Biomass to generate power

The biomass of *Prosopis juliflora* can be used to generate power. In Kenya, the private electricity producer Tower Power is planning to develop two biomass power planta in Baringo and Kwale districts. The new plant will be fed by the *Prosopis juliflora* tree. The project is set to transform the tree from a noxious weed to a cash crop when about 2,000 households begin supplying the company with the tree stems. Baringo has a *Prosopis juliflora* forest cover of about 30,000 hectares, the highest density of the invasive plant in Kenya. Tower Power estimates that the forest can serve its power plant for 10 years (Business daily 2014). Other options are briquette making.

Honey and gum

Prosopis juliflora blossoms abundantly. It is known to produce high amount of pollen that can be transformed into high-quality honey. The only constraint in dry-lands is the lack of water sources for the bees. The gum that exudate from *Prosopis juliflora* is comparable to gum Arabica and can be used in the food-cosmetic industry. Its use is constrained by the absence of toxicological tests necessary for it to enter the industrial market.

Box: Costs and Benefits

- A pod collector in Peru can pick up to 150 kg/day and earn 5 USD/day during the production season. In February, the pods sell in the market at USD 27/ton (1997) (PASIECZNIK, 2001).
- In India *Prosopis juliflora* wood is sold at INR. 80 per kg (USD 2) and charcoal is sold at Rs. 14 per kg (USD 0.33) (SAI BHASKAR REDDY, 2009).
- Clearing of one acre of infested land can cost up to USD 250/ha) (METAMETA, 2009).
- The use of *Prosopis juliflora* biochar plus manure is known to have brought about a 30-40% increase in cotton yield (SAI BHASKAR REDDY, 2009).
- For a small scale charcoal producer it is possible to earn USD 1900/year (CSDI, 2009b).

9.5 Conclusions: how to address the *Prosopis juliflora* challenge?

Based on the diverse experience documented so far, the most viable strategy appears to remove *Prosopis juliflora* altogether and keep the land 'clean' by intensive usage - and especially ensure it does not encroach river beds and in areas where this is not possible, to make use of proposes juliflora products. Efforts to completely and permanently eradicate *Prosopis juliflora* often fail to reach the objective. Pragmatic utilization of the shrub's outputs, such as wood, bark, flower and pods is a complementary approach. This can help to generate income (and improve livelihood) of the affected communities. The main element in a controlled use strategy:

- Focus on removal of *Prosopis juliflora* from water ways, highly productive land or land important for local food security. Keep close vigilance and intense use of these lands
- Land using communities should be encouraged to uproot *Prosopis juliflora* seedlings when they are still easy to remove.
- Land use planning – not allow cattle movement between areas with *Prosopis juliflora*
- Combating and utilizing *Prosopis juliflora* in communal lands should be supported. Ways must be found to empower communities to make joint efforts with governments and authorities and private sector (for instance in biomass conversion)
- Explore innovative uses such as the use of *Prosopis juliflora* bio-char or energy bio-mass
- A new body of regulations is required to facilitate the commercialization of *Prosopis juliflora* products. Policies must promote the production of charcoal and poles for fencing and construction, which until now is discouraged.

Acknowledgements

This paper is based on input of different member of the Spate Irrigation Network (www.spate-irrigation.org). Substantial contributions are acknowledged by Allah Bakhsh (Coordinator Pakistan Spate Irrigation Network), Emiru Birhane (Mekelle University, Ethiopia), A. Hakeem Elhassan (*Prosopis juliflora* expert Sudan), Ageel Ibrahim Bushara (Coordinator Sudan Spate Irrigation Network), Sharaffadin Saleh (Coordinator Yemen Spate Irrigation Network), Frank van Steenbergen, Abraham Mehari Haile (convenors spate irrigation network).

The Spate Irrigation Network supports and promotes appropriate programs and policies in spate irrigation, exchanges information on the improvement of livelihoods through a range of interventions, assists in educational development and supports in the implementation and start-up of projects in Spate irrigation.

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10. *Prosopis juliflora* Management Stakeholders Analysis in Afar National Regional State, Ethiopia

Wondimagegne Chekol, St Mary's University Addis Ababa, Ethiopia

10.1 Introduction

Prosopis juliflora julifora has invaded about more than 1.2 million hectares of land in Afar Region. Its invasion rate is estimated to be more than 50,000 hectares in the region annually (EIAR, 2010) and HAREGEWEYN et al. (2013) estimate that the area covered by *Prosopis juliflora* could increase to 145.81 km2 (27.62 %) and further to 163.06 km2 (30.89 %) by the years 2015 and 2020 respectively in Amibara. This indicates that there is need for an immediate management of *Prosopis juliflora* in the area.

Even though, *Prosopis juliflora* has positive effects on soil fertility and microclimate the plant is generally perceived negatively due to its fast invasion rate and negative impacts like loss of biodiversity, physical injury on human being and livestock, blocking access roads to farms and irrigation canals and the huge amount of money spent for clearing. Thus, so far the prevailing management approach in Ethiopia is eradication although some scholars argue that complete eradication might be impossible, favoring management through control and utilization of the plant.

Recognizing the urgent need to address this problem, several governmental and non-governmental institutions have started to get involved in the management of *Prosopis juliflora*. But so far all isolated management interventions failed to bring a lasting solution to seize the invasion. This stakeholder assessment was conducted to provide baseline information on the knowledge and experience of the institutions on *Prosopis juliflora* management, as well as their respective strengths and weaknesses. It will be asked why all previous management interventions failed so far, arguing that increased institutional coordination and clear mandates will be vital for future *Prosopis juliflora* management.

The methodologies employed in this study were review of secondary data obtained from Afar Regional Government Office to map stakeholders involved in *Prosopis juliflora* issues. Moreover, interviews with project coordinator and community facilitator of FARM AFRICA, and CARE as well as focus group discussions with the communities and Kebele Administration members were done. To analyze the data collected a descriptive analysis was used.

10.2 Results of stakeholder assessment

Main stakeholders in the management of *Prosopis juliflora* are various Government Ministries, Regional Government Bureaus, Research Organizations, Non-Government Organizations and local communities. The following assessment will focus on those stakeholders:

- that were active in previous management initiatives from which lessons can be learnt
- that could play a potential role in future management interventions due to their available resources (capital, knowledge, political power, etc.)

Governmental Stakeholders

Ministry of Agriculture

The Ministry of Agriculture (MoA) oversees the agricultural development policies on federal level. The powers and duties of the MoA include: conservation and use of forest and wildlife resources, food security, water use and small-scale irrigation, monitoring events affecting agricultural development and early warning system, promoting agricultural development, and establishing and providing agriculture and rural technology training. The MoA has three State Ministers namely; State Minister for Agricultural Development, State Minister for Livestock Development and State Minister for Natural Resources Conservation and Development.

Though the ministry is pertinent to monitor events affecting agricultural development, to set up an early-warning system, conduct quarantine controls on plants, seeds, animals and animal products brought into or taken out of the country and to take measures to prevent outbreaks of animal and plant disease and migratory pests little attention is given to the control of IAS. It was proposed by the RBIPMA- GEF project (see section on EIAR) that the MoA should assume the role of lead agency to tackle the IAS problem in the country, establishing IAS councils at all administrative levels, having their secretariats within the structure of the Ministry of Agriculture. However the proposal was not implemented up to now.

Ministry of Environment and Forest

The Environmental Protection Authority (EPA) which was established in 1995 by Proclamation No. 9/1995 was replaced by the new Ministry of Environment and Forest 2013. The Ministry takes all mandates given to Environmental Protection Authority (EPA) and has the statutory mandate to coordinate the Climate Resilient Green Economy (CRGE) planning, one of Ethiopia's current key policies in its Growth and Transformation plan, as well as the strategy for 'Reducing Emissions from Deforestation and Degradation' (REDD+).

Ministry of Water and Energy

The Ministry of Water and Energy of Ethiopia (MoWE) is responsible to 1) promote the development of water resources and energy, 2) undertake basin studies to determine the country's ground and surface water resource potential and facilitate the utilization of same, 3) determine conditions and methods required for the optimum and equitable utilization of water bodies that flow across or lie between more than one regional States, 4) undertake studies and negotiation of treaties pertaining to the utilization of boundary and trans-boundary water bodies, and follow up the implementation of same, 5) carry out studies and design/construction works to promote the expansion of medium and large irrigation dams and 6) administer dams and water structures constructed by federal budget; 7) promote the development of alternative energy sources, etc.

The Awash Water Basin Agency which is under the MoWE manages the water distribution to farms, maintenance of canals, dykes and the control of floods within its mandated areas in the Awash Basin. To perform these operational activities the office constantly clears *Prosopis juliflora* from dykes and canals with bulldozers and human labor, but without uprooting the plant. Therefore, is only a temporal eradication which involves high costs every year and even increases coppicing and reinvasion afterwards.

Ministry of Federal Affairs (MoFA)

The mandate of the Ministry of Federal Affairs is to bring equitable development in the less developed

regions like Afar, to prevent and resolve conflicts, to strengthen the Federal system and to maintain good relations between the Regions. To materialize this mandate the Ministry is coordinating the Pastoral Community Development Project (PCDP) funded by World Bank which is running different integrated development activities in Afar Region. However, *Prosopis juliflora* as a threat for development activities is not included in this project.

The Ministry's potential strength in relation to the implementation of management initiatives is that it has established community-based organizations for managing natural resources, bush clearing and use of fire and other means of rangelands management.

Afar National Regional State (ANRS)
On 7th of July 2011 the Afar Regional State issued the proclamation No. 5 to control, manage and eradicate the invasion of *Prosopis juliflora* in the Afar Region. The proclamation clearly describes the control strategy and the roles and responsibilities of the pertinent regulatory bodies at Regional, Wereda and Kebele level to implement the strategy designed to prevent, control and eradicate the encroachment of *Prosopis juliflora*. This being the strong side of the Regional Government, but its implementation on the ground is still pending.

Bureau of Pastoral and Agropastoral Development (BoPAD)
The Bureau of Pastoral and Agropastoral Development is responsible for agricultural development and natural resource management in the region. It should have a major role to implement the strategy of *Prosopis juliflora* management on regional and local level but so far the bureau is not actively working on control and management of *Prosopis juliflora* directly, except issuing bilateral agreements with development partners, giving license for marketing *Prosopis juliflora* products like charcoal, and working through its Woreda offices with NGOs engaged on *Prosopis juliflora* issues.

Research Organizations

Ethiopian Institute of Agricultural Research (EIAR)
EIAR is the most influential Ethiopian research organization in the field of IAS. It is mandated to conduct and coordinate agricultural research to provide competitive agricultural technologies that will contribute to increased agricultural productivity and nutrition quality, sustainable food security, economic development, and upkeep of natural resource and the environment in the country. EIAR has more than 15 research centers located in different parts the country, out of which one is found in Amibara Woreda (Afar) where *Prosopis juliflora* is a serious problem. Since 2000 this center has undertaken *Prosopis juliflora*-related research, and in collaboration with FARM Africa, governmental institutions and private farms, has created awareness among local pastoralists around Amibara through training and management. The center developed with FARM Africa the *Prosopis juliflora* Management Strategy for Afar National Regional State.

EIAR also acted as national executing agency for a four-year Project (2008-2012), named Removing Barriers to Invasive Plant Management in Africa (RBIPMA), funded by UNEP/GEF. The project was designed to accomplish the following objectives:

- Strengthening the enabling policy environment for IAS management
- Provision and exchange of critical information amongst key stakeholders in IAS management
- Implementation of IAS control and prevention programs
- Building capacity for sustainable IAS management

EIAR developed and submitted a Policy and Stakeholder Analysis for Invasive Plants Management to concerned stakeholders (including the MoA) in order to create awareness on prevention, control and man-

agement of *Prosopis juliflora*. Although the policy was not implemented so far it can be of value in the future. In pilot sites in Amibara EIAR enclosed certain areas, cleared them from *Prosopis juliflora* and started forage production, but since there was no follow up to control *Prosopis juliflora* and to restore rangelands the cleared land started to be reinvaded. EIAR also assisted Master students to do research on IAS but research results were not officially published.

Horn of Africa Regional Environment Centre and network (HoA-REC&N)
The Horn of Africa Regional Environment Centre and Network (HoA-REC&N) is an autonomous institution under Addis Ababa University which works on environmental concerns and sustainable development options within the Horn of Africa. It facilitates, strengthens and advocates for initiatives related to land use planning, integrated water resources management, ecosystem management, climate change and energy and value chains for sustainable products and services. Currently; it is working on the Re-Greening Program of the Horn. One part of the program included the protection of forested areas from invasive species. The center is also developing an Environmental Partnership Program on Invasive Species. In the meantime the center has started to work on *Prosopis juliflora* issues in Afar National Regional State.

Institute of Biodiversity Conservation (IBDC)
The main objective of the institute is to protect the plant genetic resources of the country and thereby, support crop improvement programs. The Institute has collected appreciable amounts of indigenous tree seeds for in-situ and ex-situ conservation, conducted conservation research and developed the National Biodiversity Strategy and Action Plan of Ethiopia (NBSAP). However, beyond acknowledging *Prosopis juliflora* as a potential serious threat to biodiversity in its strategic and action plan, it has not yet involved in any action to safeguard the biodiversity of *Prosopis juliflora* invaded areas.

Afar Pastoral and Agropastoral Research Institute (APARI)
APARI is a young Regional Research Institute, based in Semera, the capital of Afar Region. It is mandated to develop and adapt agricultural technologies that support the Afar Regional State development endeavors. Since its establishment in 2004, the institute has been undertaken research activities on *Prosopis juliflora* but suffers from lack of funding, qualified personal and basic research infrastructure.

Higher Education Institutions

Higher Education Institutions which are involved in research on *Prosopis juliflora* are: Addis Ababa University, Haramaya University, Mekele University, Semera University, Bayreuth University and Bonn University, Germany. The knowledge gained from their research findings can an asset for the management of *Prosopis juliflora* in the country.

Non-governmental organizations

FARM Africa
The British NGO FARM Africa has worked in Afar Region since 1998 implementing integrated pastoral development projects which included regular development interventions as well as livelihood based emergency services deploying an innovative pastoral extension approach- the Mobile Outreach System. It is the only stakeholder with several years of practical experience in the management of *Prosopis juliflora* in Afar Region and important lessons can be learnt from this organization. In 2001 FARM-Africa started action research on *Prosopis juliflora* management in Gewane and Amibara (Yiergalem, 2001), mobilized local communities to clear invaded land by providing hand tools and started to use the cleared land for crop production. However, this was not as effective as expected since the communities failed to use the cleared land for crop production. Instead they started to use the cleared wood for the illegal production of charcoal which was banned by the government. In order to legalize charcoal production from *Prosopis juliflora*

FARM-Africa collaborated with the regional government to organize motivated community members into cooperatives so that they could secure legal permits for the production and marketing of *Prosopis juliflora* products. To this effect, FARM- Africa developed a project known as Afar *Prosopis juliflora* Management Project (APMP Phase I, 2008-2011) funded by the Norwegian Development Fund. APMP-I was implemented in four Kebeles in Gewane and five kebeles in Amibara Woreda targeting over 4,400 households (27,500 people) with the goal of 'increasing resilience of pastoralists to environmental shocks through improved natural resource management and by institutionalizing a participatory local level *Prosopis juliflora* management system (Admasu & Yemane, 2012). The project had the following intermediate results:

- develop strategies/ techniques for *Prosopis juliflora* control for Gewane and Amibara Woredas;
- reduce *Prosopis juliflora* invasion and clear and utilize invaded areas through community management in Gewane and Amibara Woredas to improve livelihoods
- disseminate *Prosopis juliflora* management strategies for adoption in other affected Woredas

Evaluation of APMP Phase I

FARM mobilized pastoralists to clear and use the invaded areas for agriculture and pasture, to restore invaded rangeland, collect pods for the production of animal feed and to make charcoal from cleared wood. They also tried to strengthen the development of policies and regulations on *Prosopis juliflora* management (in collaboration with EIAR and Afar Region). FARM established Community Development Committees (CDCs) on Woreda level in order to prepare and implement CAP (Community Action Plans), Participatory Resource Use Plans (PRUP) and Community Development Funds (CDF). This participatory approach could be seen as a model in empowering communities in decision-making to implement and monitor *Prosopis juliflora* management activities with minimum external support. Research trails, mapping of land use and *Prosopis juliflora* invaded areas in collaboration with EAIR can be considered as a remarkable job done by FARM Africa. One major success of APMP Phase I was the integration of *Prosopis juliflora* management in the development plans of PADB, PSNP, PCDP, EIAR-FRC and APARI and the creation of strong links to several governmental stakeholders on regional and federal level. Nevertheless, the support from other stakeholders was not strong.

A project evaluation (2011) reported that the project beneficiaries cleared 545 ha of invaded land of which 179 ha was cultivated with different crops (benefiting 358 HHs with an average land holding of 0.5 ha) and the remaining 366 ha was managed for pasture land to benefit over 300 HHs (50% women). From the cultivated areas 1,210 quintals of maize, 50 quintals of sesame and 60 tons of grass were harvested in one year which is estimated to have economic value of 745,000 birr. When benefits from clearing became obvious communities in Gewane and Amibara Woredas (both targeted and non-targeted) cleared over 800 hectares of additional invaded land for crop and pasture production. Main weaknesses/failures identified were the limited scope of intervention in only few Kebeles of two Woredas while the invasion continued at an alarming rate in other Kebeles, the trend that also indigenous trees were used for charcoal, the limited interest of pastoralists to collect pods for crushing and utilization for animal feed and the limited support from the Wereda to resolve conflicts on land ownership.

APMP- Phase II

The Second phase (APMP-II) started in January 2012 in three Weredas (Amibara, Gewane and Burmudaytu) and twenty Kebeles. Originally designed for four years (2012-2015) the project phased out one year earlier due to the evaluation made by the funding organization. They came to conclusion that the management practices deployed by FARM-Africa were too slow to keep pace with the high invasion rate of *Prosopis juliflora*. In 2014 only seventeen Kebeles out the twenty Kebeles were engaged in managing *Prosopis juliflora*, the office of FARM Africa at project site was about to be closed, pod crashing activity for feed preparation had stopped, the new Briquette making machine was not functional and generally all activities seemed to collapse.

A focus group discussion with the Kebele administration and target communities revealed that the project had created motivation to work on the reclamation of invaded areas and to use the land for agriculture which helped them to generate income through sale of crops and vegetables. However, Afar people stressed that controlling *Prosopis juliflora* with the involvement of few selected Kebeles cannot stop the high speed invasion in Afar. Thus, for effective management the mobilization of people from all Kebeles (invaded and not invaded) as well as strong support from federal and regional government is needed.

Care Ethiopia
CARE Ethiopia started to work on *Prosopis juliflora* management with its program Pastoral Livelihood Initiatives II (PLI II), *Prosopis juliflora* Land Reclamation and MNCH project funded by USAID in two kebeles which it took over from FARM Africa in 2009. Following the principles and guidelines of FARM Africa CARE worked with the Gewane Wereda Pastoral Development office and community Development committees (CDC) in organizing seven groups (180HH in total) to clear land invaded by *Prosopis juliflora* and use it for crop cultivation. CARE supported the CDCs in developing Community Action Plans (CAP), providing capacity building trainings, creating links to the central markets, funding project activities such as purchase of water pump, providing technical support through its Natural Resource Management program, providing hand tools for clearing and preparing the land, providing improved seeds and agronomic training.

From a group discussion it was learned that since inception of the project in 2010 the seven groups cleared 421 hectares and used this land for crop and vegetable production. The cleared *Prosopis juliflora* wood was partly used for household consumption and for wood and charcoal sale. Generally, the reclamation and utilization of the invaded areas for crop, vegetable and forage production contributed towards income generation which directly has an effect on the food security of pastoralists. The Project has demonstrated a possible way forward to fight the invasion of *Prosopis juliflora*, though the work load for the beneficiaries was too high.

***Afar Pastoral Development* Association (APDA)**
APDA is a local nongovernmental organization with focus on health and education. APDA also includes activities to restore and protect the fragile environment of the region and acknowledges the threat posed by *Prosopis juliflora* to local pastoral communities. Due to its strong link to the Afar communities and its experience in community mobilization they are an important organization when it comes to implementing participatory forms of natural resource management.

10.3 Conclusion and recommendations

So far there is no sound governmental intervention to control the invasion. There is neither a leading institution responsible for prevention, control and management of *Prosopis juliflora* at national level nor a clear institutional mandate to deal with invasive weeds in the country. The previous interventions to manage *Prosopis juliflora* lack synergy and coordination to bring effective and satisfactory management results. Interventions and experiences of some major stakeholders like Farm Africa, the Regional Government of Afar and Ethiopian Institute for Agricultural Research have paved the way to improve the management of *Prosopis juliflora* in the coming years. It is, therefore, an opportunity to have notable potential stakeholders at national and regional level that can bring a difference in the management of *Prosopis juliflora*. Formulation of Policy document by EAIR, issued regulation on *Prosopis juliflora* management by ANRS and the management practices used by FARM- Africa, CARE and other institutions could be taken as a positive action to go about against the invasion of *Prosopis juliflora*.

However, there is still an urgent need to integrate all currently isolated efforts of the stakeholders to arrive on sustainable *Prosopis juliflora* management. In addition to this action should be taken to implement the Policy document prepared by EIAR and the regulation issued by Afar Regional Government.

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11. Experiences of managing *Prosopis juliflora* invasions by communities in Kenya: Challenges and Opportunities

Simon Choge, Kenya Forestry Research Institute, Kenya
George Muthike, Kenya Forestry Research Institute, Kenya

11.1 Introduction

The genus *Prosopis juliflora* is characterized by trees and shrubs in the family Leguminosae (Fabaceae), sub-family Mimosoideae. The genus has 44 species some with several varieties that were identified and described by BURKART (1976). Of the 44 species of the genus *Prosopis juliflora*, 40 are native to the arid and semi-arid Americas from the southern USA to Argentina and Chile, whereas three are native to Asia (P. cineraria (L.) Druce. P. farcata (Solander ex Russell) MacBride, and P. koelziana Burkart and one native to northern Africa (P. africana (Guill., Perr. & Rich.), Taubert (PASIECZNIK et al., 2001).

About half of all *Prosopis juliflora* species are of tree form while the rest are shrubs, (GALERA et al. 1992, CONY 1996). They vary widely in their growth forms, adaptability to arid conditions as well as their productivity and utilisation by humans and animals. Characteristics that have made some South American *Prosopis juliflora* species remarkable trees of choice include the rapid vegetative growth with the ability to survive and thrive in poor soils and under drought conditions (to produce wood for fuel and timber) and large amounts of sweet fruits/pods (for food and fodder). It is on this basis that about half of the American *Prosopis juliflora* species are of major ecological and economic importance and they have been introduced throughout the world, specifically over the last 200 years (PASIECZNIK et al., 2001).

However, of these introduced species outside of the native range, four species have been successful and have therefore become well established around the world. These are *Prosopis juliflora* Swartz DC and P. pallida (Humboldt & Bonpland ex Willd.), in the tropics and P. glandulosa Torrey and P. velutina Wooton, in the sub-tropics (PASIECZNIK et al. 2001, FELKER et al. 1981, HARRIS et al. 1996).

The first introduction of the American *Prosopis juliflora* species to Africa dates back to 1820 and 1900 when they were introduced to Senegal and South Africa respectively (PASIECZNIK et al., 2001). It was introduced in the Greater horn of Africa (GHOA) through the Sudan in 1917 (BROUN & MASSEY, 1929). *Prosopis juliflora* has now naturalized in dry regions of most African and Asian countries forming an important component of dryland vegetation and land scape.

The successful *Prosopis juliflora* species in the tropics and sub tropics are characterized by prolific fruiting habits, sometimes with more than two peaks in a year. The fruits are highly palatable and nutritious to livestock and humans owing to the high and often the only source of sugars, carbohydrates, and proteins in marginal areas

The seeds embedded in the fleshy fruits are hard and rarely get digested when eaten by animals, hence are mainly spread through animal droppings. Furthermore the seeds have prolonged dormancy and are capable of surviving long periods of drought because they are secure within hard protective seed coats. They also have few natural enemies, thus making most of them very viable. The high number of viable seeds that germinate and grow very fast when in contact with moisture is the cause of the high densities of invasions that out-compete other plant and pasture species with relative ease. Their success in terms of fast growth and adaptability to arid areas that have not been well harnessed is the cause of their weediness and reduction of agricultural productivity and biodiversity in areas they are growing.

Despite the early introductions to Africa in general and eastern Africa in particular, it was not until early 1960s and 1970s that many regional governments and environmental agencies initiated large scale planting of *Prosopis juliflora* as a popular species through ASAL development programmes. Its invasive potential was then little known. The El Nino rains of 1997/98 accelerated the spread of the species as a weed in Ethiopia, Kenya, Somalia and other regional countries. In Kenya and Ethiopia for example, the current coverage by *Prosopis juliflora* is estimated at between 800,000 to one million hectares in each country, and they continue to expand rapidly (CHOGE 2005, USFS 2006). The impenetrable thickets that characterise most *Prosopis juliflora* infestations have mostly out-competed grass and related rangeland forage, thus seriously conflicting with pastoralism (CHOGE et al., 2002).

Unfortunately, *Prosopis juliflora* is difficult to eradicate. Integrated eradication programmes using manual, mechanical, chemical and biological methods have given limited success largely due to little understanding of its biology. Some of these methods are effective for a short time, but *Prosopis juliflora* generally returns. This is largely because they re-grow from stumps and from massive numbers of seeds stored in the ground. Seeds usually lie dormant in the soil for many years and germination is stimulated by soil disturbance and sudden rise in moisture.

Due to the ecological and socio-economic impact of the species, there is urgent need to develop management strategies that are environmentally friendly and economically viable to bring them under control. Management through exploitation/utilization is increasingly becoming popular. With the production of fuelwood, sweet pods and relatively straight stems for timber, exploitation of *Prosopis juliflora* can be a profitable use of otherwise unproductive land. With the current rising shortages of livestock feeds, domestic and industrial sources of energy and timber, *Prosopis juliflora* potentially offers a sustainable solution to the crisis if well managed. Markets for the *Prosopis juliflora* products are developing around the world but knowledge of its range of uses needs to be promoted widely.

This paper documents the experiences of managing the *Prosopis juliflora* invasions by communities in Kenya and recommendations for the best management approaches that could be considered by the regional governments to address the menace.

11.2 Objectives

The specific objectives of the *Prosopis juliflora* spp management programme in Kenya are as follows:

- To establish a coordinated strategy for the control and management of *Prosopis juliflora* by farmers and pastoralists in Kenya
- To strengthen capabilities of communities on stands management, product harvesting, processing and utilization
- To disseminate the information on the best ways to control and manage *Prosopis juliflora* spp, including prevention of further spread of the tree to unaffected areas

11.3 Methodology

Coordination and implementation framework

Organization of the Prosopis juliflora spp management project in Kenya
The Government of Kenya has mandated the Kenya Forestry Research Institute (KEFRI) to take the leadership and coordination of the projects dealing with research and development of Prosopis juliflora species in the country. This is done in collaboration with the Kenya Forestry Service (KFS), a sister institution in the Ministry of Forestry and Wildlife. Other relevant institutions and stakeholders are also consulted regularly in order to cross fertilize and appraise the focus on research and development agenda of Prosopis juliflora species.

The first studies on status and impact of *Prosopis juliflora* in Kenya were carried out by the two institutions in 1999 to 2001. From 2005 to date, several projects on management, control and utilization of *Prosopis juliflora* species have been undertaken, the current project under ASARECA is also being implemented under this arrangement. The project sites are Baringo, Tana River and Taita Taveta Counties.

Training activities for communities
Capacity building of the Government staff and community facilitators was carried out in the initial pilot project in 2005 in Baringo District (now Baringo County). While the community facilitators still work actively in Baringo County, the Government staff has been deployed or send to perform training activities on *Prosopis juliflora* spp in target areas across the country when they are required.

Establishment of community groups
Establishment of local community groups has been a popular strategy for involving communities to manage *Prosopis juliflora* spp invasions. The process is usually delegated to the local administrators and community opinion leaders to form the groups. The bottom line is the need for fair representation of all the linguistic groups, ages, gender and other parameters decided by the communities targeted.

Technology development through field demonstrations
Piloting of *Prosopis juliflora* spp management interventions by each of the groups have been strongly advocated for. These demonstrations serve as learning centres for the communities, and are usually located at strategic places to allow maximum exposure to the community members.

These technologies included: thinning and pruning of natural stands; suppression of regeneration and coppicing through active land use. Field days are usually organized periodically to guide the community members and the general public through the demonstrations.

11.4 Results and discussion

Defining the status and impact of the species in Kenya (1999 – 2001)

The widespread complaints by pastoral communities from many places across Kenya triggered the first initiatives by the Government of Kenya to address the growing *Prosopis juliflora* problem. In response to the community's' concerns, the Government through the Kenya Forestry Research Institute (KEFRI) and Kenya Forest Service (KFS) were tasked to undertake a study on the status and impact of *Prosopis juliflora* spp invasion in the country. The study established that *Prosopis juliflora* posed a serious threat to livelihoods of pastoral communities and to the ecosystem of wetlands in the country. This was further compounded by the complete lack of knowledge and technology to manage the invasions by the local communities (Choge et al., 2002).

In addition, the Government lacks policy that guides management and control of *Prosopis juliflora* spp and other invasive species. The report formed the basis for the drafting of a Cabinet Memorandum (a technical paper detailing a current issue that requires urgent policy direction by the highest decision making organs of the Government) on the threat of *Prosopis juliflora* species to Kenya's ecosystems and the urgent need to marshal resources towards its management and control.

The second output of the report was the hosting of the first national workshop on management and control of *Prosopis juliflora* (2003) that resulted in formulating a pilot project on management, control and utilization of the species in Baringo District. The workshop also led to the formation of the first task force on management and control of *Prosopis juliflora* in Kenya hosted by KEFRI.

Initial piloting of management and control of invasions in Baringo District (2005-2007)

The Food and Agricultural Organization for the United Nations (FAO) supported the first pilot project in Baringo District on integrated management and control of *Prosopis juliflora*. The project began by intensive capacity building of the Government officials drawn from the key line Ministries and Departments as well as the communities.

Training of trainers course

The training of trainers (TOT) course was conducted with the aim of strengthening the capabilities of the Government officials and the local communities to address the *Prosopis juliflora* problem through classroom and field training. It also covered the Farmer Field School methodology and was undertaken by specialized FFS Master Trainers provided by FAO. A total 24 project facilitators drawn from the local communities (14), Government Departments (9) and NGOs (1) within the project area were trained on *Prosopis juliflora* spp management. Community facilitators were selected from the affected administrative localities across the project area.

Establishment of Farmer's Field Schools

Completion of the training of facilitators led to the next stage of establishing the Farmer's Field Schools at each of the affected localities. Facilitators worked with the local administration to democratically

select/elect about 30 local farmers as members of the group. These members elected their officials, made the group constitution and processed their application with the Department of Social Services to be formally registered and recognized as a society. After successful registration, members agreed on the days of their weekly meetings to work on their training sites. Initially, ten FFS groups were envisaged to be established one in each administrative location affected by *Prosopis juliflora* invasion.

In principle, FFS approach is based on a voluntary contribution of labour in exchange of a learning process. Unfortunately, the expectations of the local communities across the project area were very high. In the end, five groups successfully went through the registration process and actively participated in the programme with a total membership of over 200 farmers who were fully involved in the field activities. These were centered around participatory development of the technologies for managing, controlling and utilizing the invading populations of *Prosopis juliflora* trees around their respective areas.

Technology development

Thinning and pruning of natural stands

FFS is a participatory approach to extension, whereby farmers are given opportunities to make choices in the methods of production through discovery based approach. It aims to increase the capacity of groups of farmers to test new technologies in their own fields, assess results and their relevance to their particular circumstances, and interact on a more demand driven basis with the researchers and extensionists looking to these for help where they are unable to solve a specific problem amongst themselves.

As a pastoral community that keeps large herds of livestock as a major source of their livelihoods, the members of all the FFS participating in the project were more inclined to encourage the growth of grass in areas that have been heavily invaded by *Prosopis juliflora*. They therefore experimented on various thinning and pruning regimes of *Prosopis juliflora* spp that could meet their desired objective. These included thinning spacings ranging from 3m by 3m to 20m by 20m apart between trees. The findings from all the groups showed that large spacings of above 8m by 8m apart allowed high growth of natural grass cover. The large spacings also allow mechanization of the intervention areas for preparation to plant improved species of grass and/or crops. However, for mechanization to be well undertaken, stumps must be completely extracted on managed areas.

Spacings between 6m by 6m and 8m by 8m were found to have moderate populations of natural grass after clearing of *Prosopis juliflora* has been done. On the other hand, close spacings of 5m by 5m and below is recommended for areas intended for future production of construction poles and sawn wood (Choge & Okeyo, 2007).

Suppression of regeneration and coppicing

Two major reasons of the difficulties of eradication of *Prosopis juliflora* species after establishment are the huge viable underground seed bank and the coppicing ability. The FFS groups successfully developed the technologies to address these two twin issues.

They found that in order to suppress the natural regeneration on cleared areas, active land use must be practiced every time *Prosopis juliflora* is cleared. Planting of grass was found to be the most effective method of suppressing the natural regeneration. Further trials using fast growing trees in combination with grass are being done.

With regard to reduction of coppicing, killing the stumps by burning using dried manure was found to be the most effective method.

Complete extraction of stumps by digging them out was also found to be very effective but is labour intensive hence expensive.

Management and control through utilization
In South America where *Prosopis juliflora* is native, it has been exploited for several centuries as one of the major industrial wood. In the process, many rural economies in those countries have continued to rely on it to supply a growing national and international trade in processed products. Where introduced, it remains largely under-utilized. Lack of knowledge on its utilization and wise management has largely contributed to its invasiveness.

The groups were guided to demonstrate various methods of commercial production and trading of *Prosopis juliflora* wood and non-wood products. The easiest to produce were harvesting of construction poles to meet local markets around the project area such as schools and individuals. Charcoal production was also successfully demonstrated by the groups and also marketed locally. Other products made included sawn timber (hence furniture) and wood chips from otherwise useless thorny branches. Pods were used to make various local human delicacies such as cakes, chapatti (pan cakes), tea and ugali. Livestock feed formulations were also made using various mixtures of locally available crop residues.

Outscaling of the technologies (2007-2011)

Formation of local community groups in other affected areas
The technologies developed in Baringo District were further refined with support from the World Bank (Kenya Agricultural Productivity Project – KAPP) and Kennington Overseas Aid/UK (Pasiecznik et al., Choge 2006). These technologies are now being out scaled to other affected communities in the country in such Counties as Garissa, Taita Taveta, Tana River and Turkana. The approach has closely followed the Baringo example where the entry points have been through formation, registration and training of community associations. The Government of Kenya has fully endorsed the concept of management and control of *Prosopis juliflora* invasions through utilization.

The line Ministries, particularly the Ministry of Forestry and Wildlife (KEFRI and KFS), Ministry of Agriculture (National Agriculture and Livestock Extension Programme, NALEP) and the Ministry of Livestock Development (Arid lands Based Livelihoods Support Project, ALLPRO) have been encouraged to include the management of *Prosopis juliflora* as one of their core extension activities. Other national programmes (such as Arid Lands Resource Management Project under the Office of the President) have also been involved, including international organizations (eg, ASARECA). Support for the community groups mainly through training and empowerment to manage the invasions have been focussed. The status and activities of some of the active groups are shown in Annex 1.

Use of Prosopis juliflora pods as a commercial ingredient in manufacture of livestock feeds in Kenya
Aware of the potential of *Prosopis juliflora* particularly *Prosopis juliflora* pods to be utilized, as a feed resource for livestock production particularly in those areas where feed scarcity is a major constraint to livestock production during drought crises, the International Livestock Research Institute (ILRI), in consultation with KEFRI, Henry Doubleday Research Association (HDRA) and the Department for International Development (DFID) took the initiative of convening a national workshop in Kenya in 2007.

The workshop, whose theme was to link industry to the *Prosopis juliflora* resource brought together representatives of the livestock feeds industry, researchers, developers, communities, local administration and other stakeholders to share local and international experience in the use of *Prosopis juliflora* as a feed

resource. The workshop was also aimed at generating novel initiatives to catalyze the interest of feed companies on the use of *Prosopis juliflora* pods as cost effective ingredient in the formulation of livestock feeds in Kenya. This would contribute to develop one of the strategies for utilization of the abundant *Prosopis juliflora* resource as recommended by the first national workshop (2003), and in the process, turn *Prosopis juliflora* spp menace into an opportunity, minimizing the losses while maximizing income for the livestock dependent communities in the ASAL areas of Kenya and in the Greater Horn of Africa.

With *Prosopis juliflora* coverage of over 800,000 hectares of land in Kenya and expanding, over 200,000 tonnes of pods per month can be achieved if the collection is well coordinated across the country. Trials indicate that 50 people can collect 5 tonnes per day or about 150 ton/month with earnings of over Ksh 800,000/month (US$ 8,000) between them. Research has shown that milling of 1 ton of pods during processing destroys over 2 million seeds, a novel biological control of *Prosopis juliflora* spread while sustaining livelihoods (Pasiecznik, 2007).

One of the major outputs of the second national workshop (2007) was the formation of the second task force to coordinate the activities on commercialization of *Prosopis juliflora* pods in Kenya. By the end of 2007, the task force had facilitated the collection of over 25 tons of fresh *Prosopis juliflora* pods from Turkana, Baringo, Tana River and Taita Taveta Districts and delivery to Sigma Feeds Company in Nairobi for processing. The company processed over 160 tonnes of *Prosopis juliflora* based feeds by incorporating 10% of *Prosopis juliflora* into the ration, and successfully circulating the product in the local market.

Unfortunately, lack of community structures and capacity to collect the pods at the time partly contributed to the slow momentum of the initiative. This initiative is being revived through the *Prosopis juliflora* based registered community groups in Kenya. However, the current focus is for the groups to make feeds to ensure self-sufficiency to satisfy the local demand and trade in the excess products to the larger industry. Through the ASARECA project, for example, some 3 groups have each been facilitated to purchase and install small scale pods milling machine to pilot the processing of *Prosopis juliflora* pods at their respective local areas.

11.5 Recommendations on way forward

Regional approach

The *Prosopis juliflora* problem has assumed regional dimensions within the eastern and central African countries. *Prosopis juliflora* invasions are known to double every five to ten years, and impacts of the invasions are likely to be very high if intervention measures are delayed. GIZ and other organizations working in the region would be best placed to initiate a regional strategy to address the *Prosopis juliflora* invasion problem. This should be build based on the experiences from Kenya, both past and the ongoing project. Experiences from Ethiopia and Djibouti can also be useful.

The formulation of the regional strategy could begin by formation of core teams in each of the target countries in order to harmonize the approach, leveraging on the interim strategies that are already in place.

The Government of Kenya has already developed a draft national strategy under the new constitution. The strategy underlines the need for proper coordination of the *Prosopis juliflora* spp management activities at national, County and Sub County levels, with joint leadership of KEFRI and KFS in collaboration with other Government Ministries, NGOs, CBOs and development partners. The strategy focuses on management

and control of *Prosopis juliflora* species through utilization, an approach that has received a positive endorsement from many developing countries around the world.

Use of community based groups as an approach

The experiences from Kenya are beginning to show that using community based groups is the popular and realistic approach to manage *Prosopis juliflora* species invasions. Procedures for initiating such a process have been described by Choge & Muthike (2011). However, in order to strengthen and sustain the activities of the groups, the following recommendations are advanced;

- The groups must have a reliable source of income that must benefit each member directly on a regular basis, without which it will disintegrate in a matter of time as members find alternative livelihood sources. From experience, charcoal production from *Prosopis juliflora* spp is often the easiest and most convenient source of income to the groups, followed by sale of poles and pods.

- *Prosopis juliflora* spp is often considered as a common property resource because it grows on common grazing areas. Commercial production of charcoal therefore often attracts many community members most of whom are outside the formal groups. This has resulted in serious scramble for mature *Prosopis juliflora* spp trees, leading to sudden extensive vegetation clearance exposing the soil cover to erosion and degradation. Further, competition for *Prosopis juliflora* trees has also led to widespread illegal felling of indigenous trees, particularly in absence of proper supervision. It is recommended that proper and strict measures for supervision must be put in place before community groups are allowed to begin the management and product processing interventions. Follow-up measures for areas of intervention to reduce re-invasion are given in CHOGE & MUTHIKE (2011).

- For effective management of invasions by communities, it is best to zone the major invasions as a first step. Thereafter, the groups or communities are allocated specific areas within the zones. This allows some form of organized management system and encourages accountability by those allocated the specific area(s). Issuance of permits to produce and transport charcoal and other popular commercial products from the intervention areas should be linked to adherence to the rules and regulations governing the management of the invasions. For example, minimum conditions that must be met could include selective clearance to specific spacing regimes, removal/pruning branches of remnant trees to reduce shading of grass, removal of stumps to reduce coppicing/re-growths and preservation of indigenous trees among others.

- Processing of pods has been found to be generally expensive for the groups, particularly for local uses by the group members. The gums and high fibre content of the pods (and sometimes the high water content owing to their atmospheric moisture absorption tendencies) slows down their milling process hence energy input required. This could be subsidized from sales of other products such as poles and charcoal. However, prices as sold to the industrial users can be high and this may help to motivate the groups to collect and process more pods. However, more aggressive marketing efforts for the pods are required in order to make their prices competitive by having many buyers.

- In most cases, *Prosopis juliflora* spp invasions (hence commercial products derived from it) are far removed from product markets, making it very prohibitive to transport them over long distances. The Government, producers and product buyers and other stakeholders could meet

to find a long term solution to this problem in an effort to encourage harvesting and processing of pods as a strategy to manage the invasions.

- The groups must have the capacity to store large quantities of *Prosopis juliflora* pods because their fruiting is strongly seasonal. Research on the best conditions and form for long term storage should be established to minimize loses.

- There are unconfirmed fears that as communities make substantial levels of income from *Prosopis juliflora* products, they will be inclined to grow more of the weed thus worsening the current invasion status of the species. It is therefore important that the Government supervises all the *Prosopis juliflora* management activities to ensure that the objectives of the strategy are effective. Monitoring and feedback by the coordinating institutions must be done regularly to allow revision of the strategy as need arises.

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11.8 Appendix

Appendix 1: Status and activities of Prosopis juliflora based registered active community groups in Kenya

County	Names of Association/Group and membership	Activities	Level of facilitation already given	Level of income
Baringo	Naitongaa Farmers Field School (Salabani Location) (50 members)	Charcoal making, harvesting of poles and planting of grass, collecting pods	3 power saws, 1 pods milling machine, training	Over Ksh 4 million/month
	Ngambo Self Help Group	Charcoal making and harvesting of poles	20 private power saws, 1 tractor with trailor, commercial charcoal kilns, training	Over Ksh 8 million/month
	Loboi and Eldume Farmers Field Schools	Charcoal and pods collection, honey production	2 private power saws, training	Over Ksh 1 million/month
Tana River	Jabeisa Self Help Group	Charcoal, pods, poles, planting of grass	1 pods milling machine, 2 water pumps, training	Over Ksh 1 million/month
	Chewele Self Help Group	Charcoal, pods, honey	Training	Over Ksh 500,000/month
Garissa	Garissa Youth Self Help Group	Charcoal, Poles, pods	1 pods milling machine, 1 feed blocking machine	Over Ksh 500,000/month
Isiolo	Magagala Self Help Group	Charcoal, timber, pods	1 milling machine, 1 power saw	Just started
	Merti Self Help Group	Charcoal, timber, pods	1 milling machine, 1 power saw	Just started
	Garba Tulla Self Help Group		1 milling machine, 1 power saw	Just started
Taita Taveta	Taveta Mrasha Self Help Group	Charcoal, pods, honey	1 milling machine, training	Just started

(Note: 1 US$ equivalent to Ksh 100)

12. The Economics of Bush Encroachment Estimating the benefits of Savanna rehabilitation in Namibia

Hannes Etter,
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Germany

12.1 Introduction

Namibia as one of the driest countries in Sub-Saharan Africa (SSA) suffers from a specific form of land degradation, which is also considered to be a symptom of desertification. Bush encroachment is a widespread phenomenon, being an environmental and socio-economic threat and disturbance of the social-ecological system of the original savanna. The following paper presents a first approach to use the concept of an economic quantification of ecosystem services (ES) to capture the problem and to justify public expenses. These should be used to foster a restoration of the natural ecosystem state. Due to its preliminary nature not all services can be covered and a very specific scenario has been applied.

Bush encroachment is commonly understood as "the invasion and/or thickening of aggressive undesired woody species, resulting in an imbalance of the grass: bush ratio, a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses" (De Klerk, 2004). Densities vary from relatively low bush canopy of <2.000 bushes/ha to heavily encroached areas with >10.000 bushes per ha, mostly consisting of acacia-species. Invading bushes form thorny "bush walls" up to two meters high, making the area inaccessible for humans, livestock or game (Akhtar-Schuster & Schmiedel, 2011).
The intensity of bush encroachment is linked to the precipitation gradient within Namibia. The north-western and central regions with <300mm annual rainfall experience lower densities (<5000 bushes/ha) compared to the north-eastern regions with 300-600mm annual rainfall, where densities exceed 5000 bushes/ha in all areas (Mendelson et al., 2009). This can be explained by higher water competitiveness of woody plants under high precipitation (Two-layer Model by Walter and State-and-Transition Model by Doughill et al., 1999). Especially where the grass cover has been removed by grazing, a woody canopy is likely to develop and will dominate the ecosystem.

The causes for bush encroachment still remain unclear. Different explanations exist, which currently fail to explain the occurrence completely (De Klerk, 2004). The lack of explanation is being observed by scientists and farmers as well although the problem itself is being recognized since the 1950s. During annual national rangeland management conferences farmers and researchers from different Namibian institutions continue to discuss the reasons and possible actions to encounter increased bush densities (These take place during the annual national rangeland management forum. The importance that bush encroachment has can be identified by its consequent appearance at the agenda.). It is generally agreed that bush encroachment is linked to mismanagement of rangelands, mainly to overgrazing and the suppression of natural bush fires (De Klerk 2004, Christians et al. 2010, Akhtar-Schuster & Schmiedel 2011, Ward 2005). Several other factors, such as but not limited to rising CO2 concentration in the atmosphere or specific rainfall-patterns seem to further influence further encroachment (Ward 2005, Rocha et al. 2011). This lack

of knowledge systems regarding involved ecological processes leads to missing best practices on all levels and no agreements on management strategies between stakeholders to avoid a further degradation. Therefore the issue remains unsolved on the institutional level (This is commonly agreed upon between stakeholders, as observed during the 15th Rangeland Management).

The current debushing strategies are also expensive: Different methods exist to clear an area from bushing with a varying success rate and costing. Methods differ between chemical (Chemicals can be applied manually on cut stems or at intact plants of from a plane, which is considered less ecologically), biological (Browser, such as goats or game is able to consume shrubs and bushes in their initial state) and physical (The methods vary here as well. Manual cutting or bulldozing of huge areas has been observed) clearing approaches, each having high costs of clearing. According to interviewed farmers these vary between 400N$ -1200N$ (1 € = 10.18 N$ (02/2012)) and demand large sums of capital from farmers regarding an average farm size of 5000 ha (Mendelsohn et al., 2006). These high investments combined with insecurity of farmers regarding the effects of clearance of the rangeland and institutional insecurity (Current resettlement programs aiming for a redistribution of large scale farms) lead to unwillingness to encounter bush encroachment on their own behalf (Christians et al., 2010; Interview with different farmers in the area of Northern and Central Namibia). Therefore it is necessary to offer support to farmers to encourage a restoration of the original ecosystem (TEEB, 2010). The following is a first assessment of economic losses due to the degradation of the ecosystem and its services to justify public subsidies to debushing actors.

12.2 Methodology

Due to its preliminary nature and a relatively small amount of research time only certain ES have been included into the assessment. To identify relevant services a selection has been done based on the ES framework presented in the TEEB reports (TEEB, 2010), their importance to the Namibian economy and vulnerability to ecosystem degradation. A detailed description of the approach is given below.

- Food provisioning services:
  Although the agricultural sector contributes a relatively small part to the national GDP (5.03 bil. N$ or 6% including forestry (CENTRAL BANK OF NAMIBIA, 2010)) it still has a lot of potential regarding employment opportunities (CHRISTIANS et al., 2010) and ensures food security (TEEB, 2010).
- Freshwater provisioning service:
  Especially within a dry country such as Namibia a secured freshwater supply is of major importance to human security regarding drought vulnerability but also threatens economic development. A lack of water supply can cause high economic losses as recently happened (during the first half of 2010 the Rössing Mine has been shut down for three days causing losses of ~37 mil N$, see CHRISTIANS et al. 2010).
- Energy provisioning:
  Using wood resources from the encroached areas to produce energy can secure an environmental friendly energy source and helps to achieve the Namibian goal of creating an independence regarding energy production from surrounding countries (LEINONEN & ORJALA, 2008).

Food Provisioning Service

Methodology

Precipitation patterns have been identified to have the closes links to the livestock carrying capacity per hectare (IDC, 2005). Different research institutions have estimated the amount of produced meat per hectare with regard to rainfall patterns since grass production is strongly dependent on sufficient soil moisture. Bush encroachment has been found to reduce the supported kg/ha drastically. The effect of clearing

bushes varies within the literature but is commonly understood as a doubling or even tripling of the carrying capacity within one year (De Klerk 2004, De Klerk 2005). The different numbers have been compared and average amounts of kg/per/mm under natural conditions and under a woody canopy have been found:

Research by	Carrying capacity (kg/ha/mm) under natural condition	Carrying capacity (kg/ha/mm) under bush canopy
Neudamm College	9.80	5.13
De Klerk	8.10	5.13

Table 1: Carrying capacity under bush canopy. Source: VAN ECK quoted in DE KLERK (2004), DE KLERK (2006)

On the background of different estimations, the figures from the Neudamm College have been used, representing an increase of grass production by the factor 1.91 through debushing, which is a conservative scenario.

Taxes for natural persons	
Taxable Income	Rates of tax
N$ 0- N$ 40 000	Not taxable
N$40 001 - N$ 80 000	N$ 0 +27%
N$ 80 001 - N$ 200 000	N$ 10 800 +32%
N$ 200 001 - N$ 750 000	N$ 49 200 +34%
Over N$ 750 001	N$ 236 200 +37%

Table 2: Different tax classes in Namibia (Bank of Namibia, 2011)

The average farm size within the commercial sector is 5000 ha. Based on this number the herd size of farmers under their specific farming environment can be calculated by assuming a full utilization of the maximum carrying capacity of the rangeland (MET unpublished, De Klerk 2004).

Increased production due to higher carrying capacity relates directly to the income of the farmers. By applying the current tax rates, which are displayed in table 2, increased public income can be calculated directly. The additional public income from a debushed area varies between 7 N$/ha/a and 35 N$/ha/a, based on the average annual rainfall. Figure 1 displays these different zones and their related profit.

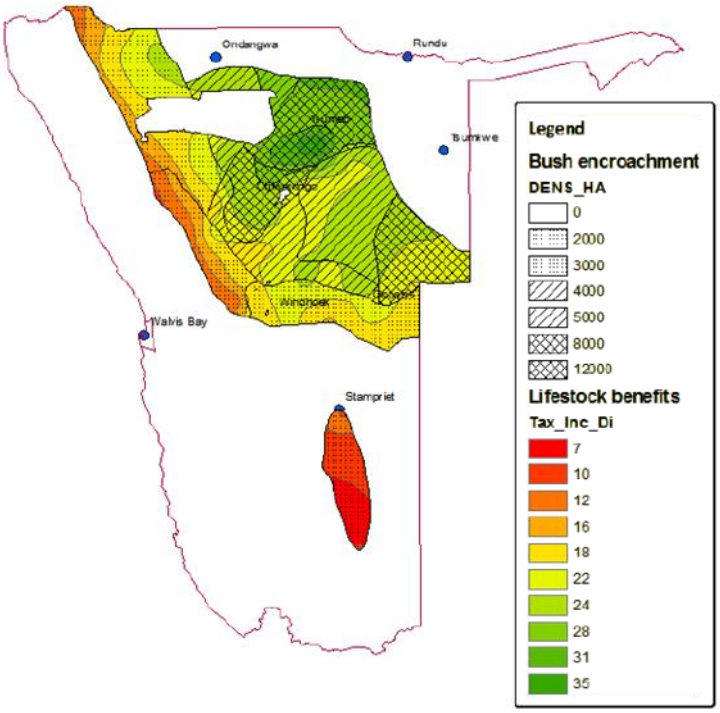

Figure 1: Distribution and amount of additional tax income from cattle farmer after bush clearing

Discussion

Beyond the economic returns, direct links can be established between the labour opportunities and the cattle numbers on farms (The relationship between the available employment opportunities and carrying capacity is 1 farm worker/LSU). Increasing cattle numbers per hectare will therefore also help to reduce the high unemployment rate (the CIA world factbook assumes 51.2% unemployment rate) and counteract poverty.

Research from Chirirboga et.al. (2008) has shown that cattle farmers experience higher risk due to climate conditions, which are aggravated by bush encroachment, since this reduces available grazing. Farmers are forced to buy fodder during years with insufficient grazing material. As a risk reduction strategy, Namibian farmers seem to sell their weaners to abattoirs in South Africa, where they can achieve higher prices than Namibian abattoirs pay for these young calves. Debushing reduces the risk for farmers by increasing available grazing land and also by enabling farmers to apply management strategies, such as herding. This means a foregone value addition within the Namibian cattle industry under bush canopy (Chirirboga et.al., 2008).

Freshwater provisioning

Methodology

Due to its generally low precipitation Namibia is classified as arid / semi-arid country with most of the area receiving below 500mm/al (Sweet & Burke, 2000), clearly limiting water resources. The few perennial rivers on national ground gain their water from the bordering countries, making Namibia's economy dependent on political agreements for a secure water supply.

Encroacher bushes have been found to increase the evapo-transpiration drastically and reduce infiltration rates into groundwater basins (Christians et al., 2010). Since most of the water resources used in Namibia are stored within groundwater basins (Mendelsohn et al. 2009, MAWF 2010), it is of major importance for a

secured supply that sufficient infiltration is guaranteed to sustain the needs of the population and the different economic sectors.

Justifying public expenses to clear areas requires a calculation of the costs from reduced infiltration and reduced water resources. Available recharge rates for Namibia are estimated for 1% of the annual precipitation as actively reaching the groundwater layer (MAWF, 2010).

The foregone groundwater resources have been calculated using a simple infiltration model and figures identified by Christians et al. (2010), which assumes that the amount of evapo-transpiration under 90% canopy cover amounts to 3.9 mil m3 per year. On the background of limited economic growth due to a lack of reliable water supply (as it has occurred throughout the recent years, i.e. the Rossing mine in 2009), rising water prices (MAWF, 2010) and high amounts of public expenditure on water infrastructure, this can be considered to be a national problem.

The applied model assumes that bush clearing doubles current recharge rates to 2%. This is much lower than the general assumptions regarding enhance recharge after debushing, but secures more secure and robust outcomes (These figures have been compared with available data on groundwater potential taken from Mendelsohn et al. (2009), which is showing the distribution of different aquifer types).

The relationship between received rainfall, original infiltration rates and those reduced by woody canopy finds a monetary representation by comparing the overall amount of lost water resources with the expenses of NamWater (LCE, 2010a), which is forced to extend its infrastructure due to reduced borehole yields (LCE, 2010a).

Selecting the water provisioning schemes located within the bush encroached areas, which have insufficient water resources until 2015 and need extension of the currently existing infrastructure offers an opportunity to identify cost, which can be related to ecosystem changes through bush encroachment under specific conditions.

The preliminary assessment shows that clearing bushes and restoring the natural ecosystem is a viable alternative for a technical solution: Even under the highly conservative assumptions (low recharge rate after restoration, small increase of borehole yields after debushing) it appears that the overall sum of expenses for debushing is lower than the expenses budgeted by NamWater for the technical solution.

Discussion
Using debushing to save public expenses for infrastructure extension appears to be a suitable approach. However, the data currently available remains insufficient and should be used with high caution. By using highly conservative assumptions more realistic data can be generated. Reduced borehole yields are general regarded as a sign of aquifer depletion. Within most of the water schemes, water usage is assumed to increase (LCE 2010a, LCE 2010b), indicating rising pressure on water provision of the ecosystem. Climate change connected to higher drought probability will aggravate this issue (Brown, 2009). Therefore it is important to develop an adapted water supply strategy in which reduced evapo-transpiration by bush control should play an important role.

Energy Provisioning

Ecosystems are known not only to sustain people by providing food and a healthy environment but also being able to produce resources, which can be used to satisfy human energy requirements (TEEB, 2010). Hereby it is possible to differentiate between so called green energy, which is considered to be ecologically sustainable and other energy sources, such as coal or other fossil fuels, which are considered to be unde-

sired or not sustainable within the process of greening the energy sector (Mfune et al. 2009, Leinonen & Orjala 2008, DRFN 2009). Namibia, as a country largely affected by climate change has set up its agenda to reform its energy sector with the goal to achieve an independence regarding the import of energy from neighboring countries and to change its energy production patterns towards more environmental friendly power production (Mfune et al., 2009).

Currently a large part of the power consumed in Namibia is being imported from surrounding countries, especially South Africa and Botswana. Therefore Namibian policy makers have identified the need for a higher power production to avoid dependencies on imported energy. The following section focuses on a technique that has been described by Leinonen & Orjala (2008), who compared different approaches and used a decentralized 10MW-power plant solution.

Methodology

To assess the benefits, which can be derived from using the biomass from encroacher bushes, a literature review has been conducted regarding the currently published literature of the public and private sector. A lot of work has been made to achieve the transformation of the energy production schemes in Namibia towards a biomass fuelled power production. Different attempts have been made to use the available material with varying harvesting and production systems. A recently published study by Leinonen & Orjala (2008) gives an overview about the different methods to use the biomass.

Relatively small power plants with a capacity of 10 MW and can be used to create a decentralized power supply network are being considered the best solution regarding costs and also feasibility (Leinonen & Orjala, 2008). Therefore they are being used within the created cost/benefit scenario. The calculations have been made for a timespan of ten years in which would mean a total amount of 540 000 MWh being produced. The costs per plant for a private investor amount to 182,5mio. N$. Since this sum is relatively high and investors are assumed to be reluctant regarding the investment risk, a public subsidy is being considered as necessary to make the construction feasible. This is of high importance to ensure that the costs per produced MWh within a biomass plant undercuts the current price of 400 N$ charged for traditionally produced energy. Under the assumption of transferred benefits from international CO2- trading schemes and 8.5% subsidy from the government it is possible to produce one MWh à 375.9 N$, which undercuts current market prices. Without this subsidy the costs exceed current prices by 160.3 N$/MWh, which makes it too costly for the market. Details regarding production costs and the subsidy calculation can be found in table 3.

With an annually harvested area of 8 600 ha it is possible to identify the costs per cleared area for the government: Under the assumption of a ten years lifespan per plant it would mean that each debushed hectare requires a subsidy of 180.37 N$ paid by public funds. Farmers within the respective area can be involved into this process by clearing their rangelands for a fixed subsidy, which covers this sum. This way public expense is being avoided and landowners have a possibility to reduce their debushing costs while energy production can take place.

As an additional benefit job creating helps especially marginalized people. Each plant creates 89 new jobs, which can help to reduce unemployment in the rural areas, where unskilled employment opportunities are required. The wage-costs are already included into the production costs and therefore further spinoff effects from job creation can directly be attributed to benefits for public income. Within the scenario the construction of four pilot plants has been assumed, which are located within the most densely encroached areas.

Costs (N$/MWh)	0 % Subsidy	8,5% Subsidy
Capital	-240,0	-218,2
Personnel	-18,8	-18,8
Maintenance	-62,5	-62,5
Fuels	-225,1	-225,1
Sum Costs	**-560,3**	**-524,6**
Income CO2	0,0	+148,76
Full Costs per MWh	**560,3**	**375,9**

Table 3: Subsidy calculations for a 10 MW plant (Figures taken from LEINONEN & ORJALA, 2008)

Discussion

The advantage of using the woody biomass for energy production is clearly that otherwise useless material is being used on an ecological sustainable base and benefits the society. Nonetheless this approach has its own limitations:

There are several discussions regarding the best method to use the woody material for energy production: This varies from the traditional charcoaling, chemical combusting to the usage of bush material in the central power plant, which is currently running on imported coal. The different methods have been extensively discussed by Leinonen & Orjala (2008). Still different voices exist regarding the suitability of the methods (SAIEA 2009, CSA 2007).

As mentioned earlier bush clearing should be done according to standards, which secure environmental sustainability, which often collides with efficient harvesting methods. It is therefore difficult to assess the exact benefits, which can be derived from the harvesting. The used number in this report has been estimated by different actors and promises to be a reliable estimation. The implementation requires a close cooperation between the executing ministries and the current main energy supplier, NamPower, who manages the grid network throughout Namibia. Issues such as energy feed-in variability and voltage adaption needs to be sorted out to successfully implement a bush-fed power network. Since they have been researching this issue as well, stakeholders from the DRFN should be involved in this process as well.

Other services

Caron sequestration

Within the scientific community there is an intensive discussion regarding the effect of bush clearing on the carbon stocks of the savanna. On the background of the often discussed relevance of the savanna ecosystem regarding global carbon storage and the vast area of Namibia's rangeland this appears to be an important factor (FAO, 2010).

Increasing woody canopy is usually assumed to raise the carbon stored within the ecosystem (Programs as the REDD program specially aim at increasing woody canopy. See also TEEB 2010). The encroaching bushes also represent a massive amount of stored carbon. Assuming an average biomass of 10t per hectare (Leinonen & Orjala, 2008), of which 50% consists of stored carbon this amounts to 55 mil. tons of carbon. Op-

posing this effect are insights by Jackson et al. (2003), who have research the amount of soil organic carbon (SOC) under bush canopy. Their results indicate that under higher rainfall (above 300mm) the sequestrated carbon within the soil is being reduced. This reduction is being accompanied by a steady state of the encroached system with regards to biomass: Whilst the bush infested areas do not encounter changes regarding their growth stages after reaching the climax vegetation grazed grassland regrow after the grazing and can therefore bind carbon annually.

This means that it appears to be reasonable to assume that the loss of aboveground carbon stocks from bushes can be compensated over a certain time scale. To identify concrete figures it is necessary to implement further research regarding the SOC stocks under bush canopy.

Tourism & recreation

Tourism is considered as one of the most important sectors within the future development of the Namibian economy (Turpie et al., 2004). In 2007 the overall contribution of the travel & tourism industry amounted to 15.1% of the Namibian GDP and is projected to increase up to 22.4% in 2017 (DRFN, 2009). It is therefore of high interest for Namibia to increase its potential and maintain the services that are sought by tourists. Contrary to the projected development of the tourism sector is the declining growth in arrival numbers during the recent years. Table 4 shows a decline in the growth rate since 2007 regarding arriving tourists. This is accompanied by a high utilization of the areas that have been identified to have a high touristic potential (Mendelsohn et al., 2009).

2005	**2006**	**2007**	**2007**	**2008**	**2009**
777.890	833.345	928.912	931.111	980 173	984 099

Table 4: Arrival numbers of tourists in Namibia (NTB, 2011)

Encroacher bushes do limit the touristic value of Namibia's savanna severely. All interviewed lodge owners and game farmers that offer game drives and safaris have mentioned limitations and reduced income due to bush thickening. This is partially caused by higher costs for the fodder, which relates to the above mentioned limitations in grass production and also forces game farmers to buy additional fodder. In addition to that thick bushes limit the main characteristics requested by tourists regarding Namibia's landscape. SIAPAC (2007) has undertaken a survey focusing on the desired features by tourists. Requested landscape services by tourists are severely limited by higher bush densities: Wildlife spotting is difficult since dense bush prevents sights above a distance of 20m and also changes the behavior of game regarding human contact (Interview with game farmers). The traditional savanna landscape is changed by bushes: Tourists as well as farmers report that high bush densities are less desired. Therefore it should be considered to clear bushes especially within the areas with high tourism potential and along the major roads in Namibia to meet the tourists' demands and to maintain and enhance the touristic value of the Namibian savanna. This will support a further development of the tourism and its capacities.

Climate change adaptation

The removal of encroacher bushes can also contribute to a development, which is better adapted to the future impact of climate change. In alignment to the climate change adaptation strategy, these can be summarized under the following points:

- Food security and sustainable resource base:
  The background of the above mentioned effects that bush encroachment has regarding land productivity reveals this connection. Removing bush can therefore be related to a more adapted and secure livestock and game production system ensuring the threatened food secu-

rity. Drought adaptation also requires sufficient water provision, which has already been discussed above.

- Sustainable water resources:
  Due to the reduced water availability caused by encroacher bushes clearing should be considered within climate change adaptation programs as well. The already threatened water availability will be aggravated by reduced rainfall within the upcoming decades (REID et al., 2007) and very available strategy should be utilized to increase the water resource base. This relates to human wellbeing as well, since insufficient water resources often lead to consumption of unsuitable water resources. Besides causing health concerns this also reduces economic income: mil 86.73 US$ are being lost every day due to sickness, absenteeism or lowered productivity associated with poor water supply (MFUNE et al., 2009). More and easier accessible water usually leads to safer water supply.
- Bush fueled power production can contribute to innovating and the Namibian energy sector, creating self-reliance and independency from imports.

Based on the overlaps of the climate change strategy and action plans and the effects of bush clearing it is justifiable to use funds from climate change projects to support debushing efforts.

Medical resources & poverty alleviation

The original Namibian savanna contains a wide variety of species, of which several are known to have a medical use. This is being increasingly acknowledged and on the background of the latest CBD new ABS schemes are being implemented, which can be of high importance for Namibia as well. One of the most important medical plants in Namibia is of Harpagophytum procumbens, which is commonly known as "Devils Claw" internationally recognized, produced and sold (Cole & Du Pleiss, 2001).

The distribution and favored climatic conditions of the Devils Claw in Namibia in currently insufficiently understood. Mendelsohn et al. (2009) give a rough overview about the mapped hotspots for harvesting. Nonetheless is known that dense bush canopy hinders the growth of the plants and makes the harvesting process impossible (Ellis, 2009). Clearing bushes in the communal areas, where the Devil's Claw is usually be found, can therefore enhance harvesting and/or increase the yields for the local people in the region. Since these are often impoverished communities in rural areas these benefits will be directly attributed to poverty alleviation and improvement of rural livelihoods, as observed in the eastern part of Namibia.

12.3 Results

The benefits of the food and water provisioning services as well as the energy production have been combined and calculated regarding to their spatial variations. This enhances the identification of regions with varying priority regarding future debushing areas. It also can help to justify a spatially differentiated amount of subsidies, which can be paid regarding to the relevant benefits that emerge within the specific region. Appendix 1 shows the distribution of benefits within the encroached areas in Northern and Central Namibia. The benefits have been calculated over a timespan of ten years to include not only onset benefits but ensure long term viability and regards to accumulated gains. It becomes clear that within the largest parts of Namibia public expenses from 150-250 N$/ha based on increased tax income can be justified, with is indicated by the orange areas.

The dark green shapes represent areas, where the overall benefits of clearing a hectare of encroacher species to restore the natural state exceeds the assumed clearing costs of 800 N$/ha. Therefore the full costs of bush-clearing can be justified to be paid by public funds, since they will be not only re-gained after 10 years but further income could be identified. These are the areas, where additional to the gains from in-

creased carrying capacity from livestock farming benefits from the saved water infrastructure extension expenses and the biomass-use in small 10MW power plants can be combined

The dark red areas are characterized by low precipitation; therefore the rainfall-depending livestock potential is lower, reducing the increased income after debushing, which is being reflected in debushing benefits between 0 and 150 N$/ha after ten years. This makes these areas less feasible for rewarding debushing measures, since there are no other services. These are also the areas which are less severely encroached and the overall population density is also lower than in the areas with high rewards after debushing (Mendelsohn et al., 2009). It might be reasonable to exclude these from the debushing plans during the implementation.

	Costs/ha (N$)	**Bulk-Sum (N$)**
Without ES benefits	800	21.438.733.000
Including ES benefits	470	12.607.183.635

Table 5: Costs for debushing with and without ES profits.

In sum the overall income from restored ES that can be used to pay for the restoration amounts to 8.8 trillion N$. This relates to ~58 % of the debushing costs per hectare can be funded from public sources by cross-subsidization, which will be returned after ten years. Aside from the spared water infrastructure savings the benefits from increased livestock production and the income from power plants after the ten years will continue to create benefits therefore increasing the overall benefit. However for the debushing project the assumed timespan should remain ten years.

12.4 Discussion & Outlook

It has been shown that calculating ES returns as a justification for debushing efforts brings important insights. Still, the research must be extended to include other economic before implementing a debushing project based on the present insights:

The current use of the savannas in Namibia does not reflect the natural ecosystem structure. The introduction of livestock, especially the currently dominating cattle breeding system already imposes a disturbance within the ecosystem. Game is more adapted to the dry conditions within Southern Africa and utilizes the entity of the available vegetation for fodder. Further assessment of feasible rangeland management strategies in accordance with the issue of bush encroachment is needed (MET unpublished, this is supported by the PolyTech of Namibia with different decision support systems and related research), since there is still large disagreement within the farmer and scientific community (Results from the 15th rangeland management forum in 2011).

Using game as an alternative for farming can increase the income for farmers, as several assessments have shown. Game provides the opportunity to combine income opportunities from tourism and meat sales as different business models are already showing in Namibia (Interview with safari lodges and game farmers). Since game species usually browse bushes, they can be utilized to reduce the bush canopy towards its initial state and can be used as an additional bush control. A subsidy may be feasible increase willingness of cattle farmers to shift towards game or mixed farming as a strategy to maintain cleared areas.

The current estimations are highly sensible to variations of the number and performance of the implemented power plants as well as to changes in the number of included water schemes. These figures are important regarding the saved expenses; increasing the numbers of power plants or water schemes will add more resources to a possible subsidy pool. Therefore the figures given above should be used as a guideline or as a first draft of a scenario and must not be taken out of the context.

The present paper does not include spinoff effects from labor creation and growth in the related industries on a quantitative basis. Although they could be identified in different sectors further estimations are required to identify reliable figures. Including these, especially on the background of a long term implementation will increase possible gains. Therefore it should be kept in mind that additional income is to be expected. Also the discount rate needs to be identified for the various sectors to derive the exact figures.

An important question after calculating the benefits is the implementation into policy making processes. Since the present paper represents a first approach to assess the losses from ecosystem degradation based on the ES, no proposals have been made to realize these gains. Special attention needs to be paid to the mode of debushing support from the government, which can be made in kind (labor, material etc.) or via financial support (loans, direct payments), but also to the institutional development. An authority is needed that secures the proper implementation of debushing regarding ecological and social questions as well as a legal framework securing that the required aftercare and rangeland maintenance will be in place.

Once these mechanisms are in place it will be possible to implement the restoration on an economically and ecologically sound base.

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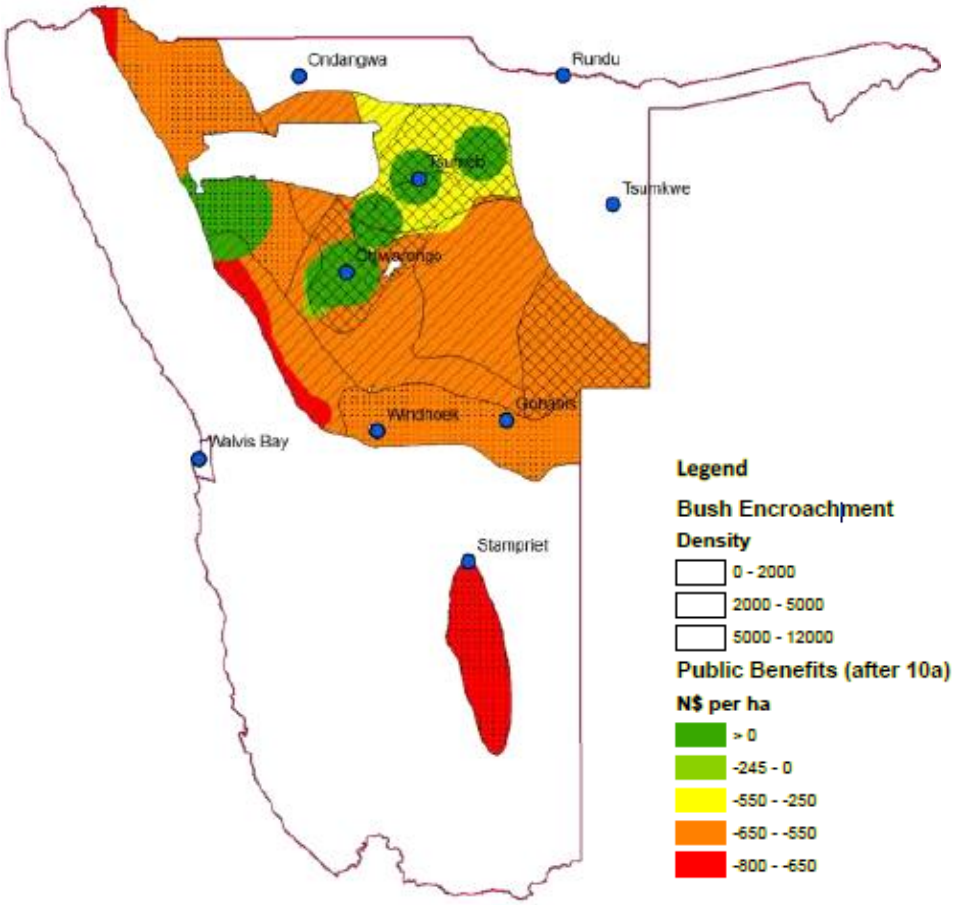
12.7 Appendix

Appendix 1: Distribution of public benefits from bush clearing in relation to the different uses.



13. Socioeconomic and Ecological Impacts of *Prosopis juliflora* Invasion in Gewane and Buremudaytu Woredas of the Afar Region

Herrie Hamedu, Food and Agriculture Organization (FAO) Afar, Ethiopia

13.1 Introduction

Afar Region is one of the nine regional states in Ethiopia, located in the northeastern part of the country with a total population of 1,390,273 (CSA, 2007). Most of the people (about 90%) in the region are leading a pastoralist way of life while the remaining proportion are either agro-pastoralists or earn their living from other livelihood activities such as petty trade, charcoal making, labor wedge, etc. Livestock in Afar are the main livelihood assets which serve mainly as source of food and income. The livestock population in the region comprises 2,318,220 cattle, 2,499,640 sheep, 4,444,290 goats, 859,580 camels, 187450 asses, 3160 mules, and 900 horses (CSA, 2005). Despite this huge livestock resource the benefit received from the sector both by individual households and national and regional governments is not too much. Livestock production in the Region is constrained by seasonal feed shortage, seasonal water scarcity, frequent occurrence of livestock diseases, low genetic potential of indigenous stock, cultural taboos against sales of livestock and livestock products, poor linkage of livestock production to market outlets, recurrent drought and institutional problems. The problem associated with livestock feed shortage is further complicated by the introduction and expansion of unwanted bushes like *Prosopis juliflora*. The rapid expansion of *Prosopis juliflora* and other weed plants at the expense of important grass and tree species is considered as a major threat for pastoralist livelihood in the Region. *Prosopis juliflora* invasion is also hindering crop production through claiming agricultural lands and serving as a hiding place for crop pests and wild animals. Although there is no clear policy or strategy at national or regional level there have been a number of efforts made by government and non-governmental organizations to control the speared and prevent the impact of *Prosopis juliflora* on livelihoods of pastoral and agro-pastoral communities in Afar. The control measures used include clearance by uprooting the tree or burning; use of the tree for other purposes such as charcoal making, house construction, fence construction and others; collection and crushing of tree pods and continuous use as livestock feeds. Studying the socioeconomic and environmental impacts of *Prosopis juliflora* from the affected communities' perspectives is essential to design and plan sustainable control and prevention strategies. It would enable one to identify the communities' perception regarding the plant, determine the negative and positive impacts of the invasion by *Prosopis juliflora* as perceived by the community and understand the solutions in the context of the local social, cultural and environmental conditions. This study has been planned with the aim of identifying and understanding the major socio-economic impacts of the spread of *Prosopis juliflora* on pastoral and agro-pastoral livelihoods in the Afar Region.

13.2 Study methodology

This study was conducted in Gewane and Buremudaytu woredas of Afar Region, which are located in the middle Awash River Basin. Four kebeles were selected purposely from each of the woredas and focus group discussion and key informants interview were carried out in each of the selected kebele. The kebeles selected in Gewane were Urafita, Yigile, Gela'ela'dura, and Gebeyabora while the ones selected in Buremudaytu were Debel, Gefrem, Kode'e and Bi'edaforo. For the key informants' interview, a total of 4 individuals (elder, clan leader, kebele administrator and women's representative) who were believed to be resourceful regarding issues related to the community were included in the study from each selected kebele. A questionnaire format was prepared and one visit interview was carried out to collect qualitative data from key informants. The focus group discussion was carried out in each selected kebele with a group of community members comprising 15 individuals with a mix of gender, age group and social status. The number of females involved in each focus group discussion ranged from 3 to 5. A check-list was prepared and an open kind of discussion was held. Data collected was systematically categorized and analyzed.

13.3 Findings

Historical trend of *Prosopis juliflora* invasion

Prosopis juliflora was first introduced into the Gewane area around 1980 by the Ethiopian Government as part of the efforts of the Government to fight desertification in the country. Every household in the vicinity of state farms in the woreda was provided with seedlings of *Prosopis juliflora* to plant them around the homestead. The households were required to care for the seedlings and damaging the seedling or the tree in any way was considered as a serious offense and was punishable. After the trees started to produce seeds the tree spread fast. At the moment (24 years after introduction), there is no any kebele in Gewane woreda which is not invaded by *Prosopis juliflora*. Homestead areas, river-banks, grazing lands, croplands and roads are all invaded and the only areas free of *Prosopis juliflora* are lands cultivated by commercial farms. In Buremudaytu *Prosopis juliflora* was introduced in 1990. It was first introduced in Debel Kebele and Meteka State Farm and spread to Kuda kebele initially and invaded the rest parts of the woreda in few years' time. Before 10 year only 20-30% of the land in the woreda was covered by *Prosopis juliflora* while currently the *Prosopis juliflora* invasion covers all areas without any exception (see Ayanu proceedings).

Local perceptions on *Prosopis juliflora* invasion and ecological problems

At the beginning of the introduction of the tree it was very much liked by the local communities and it was considered to be a relief from the intense sun since it serves as a shade and resting place. As the spread of the tree progressed and displaced native grasses and trees, local communities became increasingly worried and their perception shifted completely towards the negative. Currently, the local communities have become so desperate that they are short of words to explain their hatred towards the tree. Most of the communities believe that the tree is a wrath from Allah for their wrong doings and the lasting solution too comes from Him. Pastoralists and agro-pastoralists in the studied areas have been challenged by a number of ecological problems, which they have been fighting for many years. Among these ecological problems the most commonly mentioned are reduced volume of Awash River, recurrent drought, invasion of land by *Prosopis juliflora* and seasonal flooding. In most of the cases, *Prosopis juliflora* invasion has been rated as the second most important ecological problem next to reduced volume of Awash River. In some cases in Buremudaytu, the invasion of land by *Prosopis juliflora* and the associate problems were rated as the first most important ecological/environmental problems. In terms of impact, the visited communities in all studied areas believe that *Prosopis juliflora* invasion has a wider, profound and long standing impact than

the other ecological problems. It affects almost all livelihood systems (especially pastoralism and agro-pastoralism) and social groups.

Charcoal making using the invasive tree has become one of the control measures introduced by NGOs, which created a group within the local community which is gaining substantial economic benefit from the business (see Datona, proceedings). These people, representing a very small proportion of the local communities, consider *Prosopis juliflora* as a gift from Allah and they favor the spread of the tree. This has compromised the control efforts by GOs and NGOs.

Impact of *Prosopis juliflora* invasion on land use and livelihood systems

The major livelihood systems in Gewane and Buremudaytu woredas are pastoralism and agro-pastoralism. There are few individuals engaged in charcoal making, petty trade and labor wedge. Due to invasion of rangelands and replacement of highly nutritive tree and grass species by *Prosopis juliflora* livestock production has been affected by shortage of feed and hence the livestock herd size and individual animal productivity has been reduced substantially in the past 20 years. Livestock production has been also threatened by injuries on livestock caused by the thorn of the tree and gastrointestinal disorders following the eating of the tree pods. The survival of livestock has been also endangered by the high number of wild predators (lions and hyenas) hiding in the thick bushes of *Prosopis juliflora*. People have been thus discouraged to continue with livestock production and hence opted for other livelihood systems mainly crop production, charcoal making, petty trade and selling labor to some extent. However, crop production too is being seriously constrained by the negative impacts of *Prosopis juliflora*. Land cleared for crop production is always reclaimed by *Prosopis juliflora* during fallow period and hence agro-pastoralists are required to clear land every season they want to cultivate crop. Hence crop production is becoming laborious and discouraging business. According to the communities' perception, *Prosopis juliflora* competes for water and soil nutrients with crop, grasses and edible tree species. The invasion of land by *Prosopis juliflora* has gone to the extent of displacing people from their homestead and forcing them to aggregate in certain localities, which is not the custom of Afar people, leading to intensive use of land in settlement areas. In Buremudaytu, the proportion of people engaged in charcoal making is by far lower than the one in Gewane area and agro-pastoral livelihood activity is more common in Buremudaytu than in Gewane.

Impact of *Prosopis juliflora* invasion on human health

The visited communities explained that the impact of *Prosopis juliflora* on human health has a complex nature. The thorns of the plant are inflicting wounds on legs, hands and eyes causing blindness, lameness and even amputation of legs and hands due to infection of wounds. People are becoming disabled and could not perform their day to day duties and are exposed for food insecurity. People especially children, women and the elderly are suffering from malnutrition causes by the shortage of milk at household level. Additionally, their immunity level is very poor and thus they easily succumb to diseases. Children feeding on the *Prosopis juliflora* pods are suffering from impaction and constipation. People are also being prayed by lions and hyenas, which are breeding and hiding in the thick *Prosopis juliflora* bush. The high humidity and ambient temperature favors the breeding of mosquitos and hence facilitates the spread of malaria in affected areas.

Impact of *Prosopis juliflora* invasion on ecology

In Gewane and Buremudaytu woredas, *Prosopis juliflora* is claimed to affect the ecology and environment in the affected areas. It is completely impossible for other tree and grass species to grow in areas invaded by *Prosopis juliflora*. Therefore, the biodiversity of plants and animals is being degraded so that many species of edible trees and grasses are disappearing. Pastoralists are compelled to keep more small ruminants and

are destocking or losing cattle and camels. The thick bush created by the tree attracts many wildlife including lions, hyenas, wild pig, hedgehog, monkeys, rodents and others. The bush is also serving as a breeding site for pests and insects and their population is increasing in the affected areas. *Prosopis juliflora* is also impacting the microclimate in affected areas in that it increases ambient temperature and humidity. The invasion of riverbanks by *Prosopis juliflora* favors siltation and blockage of irrigation canals which divert the course of Awash River and hence causes flooding in some areas while blocking drainage to other areas. Intensive land use caused by *Prosopis juliflora* is resulting in land degradation and depletion of rangelands.

Impact of *Prosopis juliflora* invasion on socio-cultural conditions

The visited communities in Gewane and Buremudaytu woredas stated that the *Prosopis juliflora* invasion is also affecting their settlement pattern, in that they have been pushed away from their settlement areas and forced to move and aggregate very close to each other. This brings people and livestock from different localities and clan lines together and paves the way for resource based conflict. Road blockage by *Prosopis juliflora* is prohibiting peoples' free movement for different social activities and also created scarcity of land for socio-cultural activities like marriage, funeral and cultural ceremonies. The *Prosopis juliflora* invasion made many people destitute and hence are in need of help. As the culture of Afar people entails shouldering responsibilities for relatives and clan members, the destitute people are becoming additional burden on a few better-of families. *Prosopis juliflora* invasion is also forcing people to migrate to very far places even crossing the border with Amhara Region. This situation too is exposing the pastoral communities to cross-border resource based conflicts. The culture and social norms of the Afar people in the study areas have been diluted by people from other areas in the country coming to Gewane and Buremudaytu mainly for charcoal making and also as aides to the flourishing crop production in the areas. These outsiders are bringing new culture and behaviors (alcohol drinking, commercial sex and unprecedented crimes) to the local community. The business of charcoal making is also creating a new economic elite group mainly composed of members of local administration, tribal leaders and many outsiders. These groups of people are becoming highly influential in the communities and are undermining the role of customary institutions in natural resource management.

Vulnerability of the affected population and the environment

Communities in Gewane have become vulnerable to invasion by *Prosopis juliflora* due to the dry and hot climatic condition prevailing in the area, the reduced volume of Awash River, the livelihood systems (charcoal making business and pastoralism), cultural taboos and the large population of wild animals (herbivores and omnivores). Furthermore, the spread of the tree to virgin areas in the surrounding is enhanced by the seasonal migration of livestock in search of feed and water. The large population of wild life specially herbivores and omnivores (wild pig and monkeys) inhabiting the *Prosopis juliflora* bush are partly responsible for the spread of the tree. Moreover, the traditional habit or culture of Afar prohibits cutting of trees and killing of wildlife. This culture has been influencing the local communities negatively at the beginning of the introduction of the tree in their fight against *Prosopis juliflora*. It has been difficult for them to accept removal of the tree either by cutting, uprooting or burning as a solution to the problem. Their culture of co-excising with wildlife without any killings also favored the increase in the population of wild herbivores and omnivores, which serve as carriers and incubators of the seed of the tree.

The impacts of *Prosopis juliflora* invasion have been more severe on pastoralists from livelihood groups. These people base their livelihood on livestock rearing and thus are seriously constrained by livestock feed shortage and livestock diseases caused by *Prosopis juliflora* invasion. Therefore, significant proportion of pastoralists have been abandoning livestock rearing and are changing their livelihood mainly to agro-pastoralism and other options like charcoal making, petty trade and labor wedge. Children, women and elders are the most affected from social groups, who are in need of balanced nutrition due to their age and

biological requirements. The reduced livestock productivity caused by *Prosopis juliflora* invasion compromises the availability of milk for household consumption mainly to these groups of people. On the other hand, these groups of people are the ones responsible for livestock herding and hence are more exposed to health problems associated with *Prosopis juliflora* invasion.

Mitigation measures/coping strategies

Most of the climatic problems the local communities have been facing are seasonal and can be managed through seasonal interventions like migration to other places in search of rangeland resources, intra-clan patronage and looking for temporary aid from GOs and NGOs. However, the problem associated with *Prosopis juliflora* invasion is different. It can't be controlled by seasonal interventions and needs a lasting solution. The local communities have been trying their best to control the spread of *Prosopis juliflora* and fight its impact through various means. The most common mitigation measure currently employed by the communities to control the spread of *Prosopis juliflora* is clearance of the tree by cutting and burning. Usage of *Prosopis juliflora* tree for different purposes like charcoal making and fence and house construction too have been considered as mitigation measures. However, the communities also believed usage of *Prosopis juliflora* tree for these purposes have been also contributing for the spread of the tree in that in most of the cases the tree is removed by cutting and burning without uprooting. When the tree is cut, the pods are given to livestock to feed on it, which further complicates the problem. There is serious concern by the interviewed communities that people engaged in charcoal making are in favor of the spread of the tree and hence are acting against the control efforts (don't uproot the tree while removing it), despite the huge economic return to a few proportion of the local community due to the business. Moreover, they are also making use of other acacia tree species, which are leftovers of the negative impacts of *Prosopis juliflora* invasion, for charcoal making. This further degrades the ecology and creates a fertile ground for *Prosopis juliflora* to reclaim cleared land. The communities have been also trying to cope with the impacts of *Prosopis juliflora* invasion by engaging themselves into other livelihood activities like crop production and labor wedge, migration to other places not invaded by the tree and also looking for help from relatives. Despite the substantial socio-economic benefits agro-pastoralists get from crop production, they are subjected to various socio-cultural stresses. Since people in the studied areas pastoralists are new to the business of crop production and have to learn how to do it, they need to engage with other communities from highland areas who help them in land clearing and other activities. The communities believe that this would expose them to the risk of dilution of their cultural and social norms. The land ownership pattern will shift from communal to private and hence there will also be risks of resource based conflict for water (for irrigation) and land for crop production. Crop production can also create wealth classes and result in unbalanced and inequitable control over resources. The visited communities also believe that the most effective way of controlling the spread of the invasive tree and the one favored by them is removal of the tree by uprooting and subsequently continuous use of the cleared land for agricultural activities mainly for irrigation based crop production and rangeland development. They believe that they have a strong commitment to bring a lasting solution to the problem and hence are ready to provide anything in their capacity. They are ready to provide labor and land resources but are in shortage of capital and technology resources. They are, therefore, in need of supports like provision of agricultural tools, machineries, water pumps, improved crop seed varieties and other agricultural technologies. In most of the cases, the visited communities are not optimistic about the idea of controlling the spread of the *Prosopis juliflora* through its utilization for fear of conflict of interest among some members of the communities who are benefiting from charcoal making.

13.4 Conclusions and recommendations

Prosopis juliflora invasion is now becoming a nightmare to communities in Gewane and Buremudaytu woredas. They are out of words to express the negative impacts of the invasive tree on their communities. This assessment revealed that the socio-economic impacts of the invasion by *Prosopis juliflora* are diverse and so complex touching every angle of the life style of pastoral and agro-pastoral communities in the studied areas. Virtually all livelihood systems are affected by *Prosopis juliflora* invasion but pastoralist way of livelihood is the most seriously threatened due to the severe impact of the invasion on rangelands and the overall ecology. The *Prosopis juliflora* invasion is also affecting the microclimate in the studied areas and hence causing imbalance in the ecology. This imbalance in the ecology is also changing the profile of the biodiversity of animal (both domestic and wild) and plant (edible and non-edible) species prevailing in the affected areas. The limited rangeland resource is also creating a fertile ground for resource based conflicts within and among Afar clans and neighboring ethnic groups in the affected areas. The overall impact of the problem is affecting practically all sects of the communities without any significant distinction but due to age and biological factors the impact seems to be more serious on children, women and elders. Pastoralists in the affected areas have tried to their best to control the spread of the tree but it seems they are now defeated by the tree and desperate to get any solution from anywhere. Some of the control measures employed so far like utilization of the tree by charcoal making are aggravating the situation and are becoming threats for the whole concept of eradication of the tree due to conflict of interest. The communities believe the most effective way of controlling the spread or even eradiating the tree is its removal by uprooting and continuous use of land reclaimed from *Prosopis juliflora* for development purposes like irrigation based agriculture and/or rangeland development.

Based on the above conclusions the following are recommended:

- The *Prosopis juliflora* invasion needs to be controlled and the grazing and crop lands covered by the tree have to be reclaimed. However, in designing, planning and implementing intervention measures against *Prosopis juliflora* the role of the local community should not be undermined. It is important thus to undertake socio-cultural feasibility studies before barging for actions;
- There should be a long-term and integrated plan to clear the land covered by *Prosopis juliflora* and introduce irrigation based agriculture and rangeland development. However, as stated above, this kind of intervention needs to be critically evaluated as to the potential direct benefits to the local people;
- In the meantime, the 'control through utilization' method should be widely employed in the affected areas. This needs to be done along with creation of awareness among the community about the potential merits of the tree, establishing community groups controlling and ensuring the proper removal of the tree for different purposes, giving hands-on skills on processing the tree and its parts for different purposes, organization of producers' and marketing cooperatives, advocacy and promotion work on potential products from processing of *Prosopis juliflora* and creation of market linkage;
- The local customary institutions have been highly instrumental in keeping the ecological balance and managing the equitable use of natural resources. It is essential thus to revitalize and strengthen these customary institutions in the future to ensure community based natural resource management;
- The socio-economic impact of *Prosopis juliflora* in pastoral and agro-pastoral communities is immense and complex. Further studies should be carried out using mathematical models to quantify the impacts in economic terms and weigh the relative benefits gained through controlling its spread or eradication.

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14. *Prosopis juliflora* in Yemen

Sharafaddin A.A. Saleh, Sana'a University, Yemen
Abdo-alkreem Ahmed Ameen, Tihama Development Authority, Yemen

The following text is an extract from the Practical Note in Spate irrigation no. 23"Planting mesquite tree (alghfaf, aalwel, aalsysaban) in Spate Areas in Yemen"

14.1 Introduction

The mesquite tree (Yemenite name for *Prosopis juliflora*) acquired great attention from countries, organizations and projects working in the forestry sector, fighting desertification in arid and semi-arid areas in Africa and the Arab Peninsula. It has shown a big success in the fixation of sand dunes and their transformation into forests in Yemen (especially in Tihama region, Abyan, Lahj, Aden, Shabwah, Mrib and Hadramout). It provides the local communities with numerous products such as furniture and construction wood, fire wood, and its leaves, branches and pods are used as animal fodder with high nutritious value. Despite its vast beneficial effects, *Prosopis juliflora* is posing a real challenge these days due to its fast growth and uncontrolled spreading, especially to wadis, irrigation channels and agricultural lands.

14.2 Characteristics of *Prosopis juliflora* in Yemen

The mesquite plant is locally called Alsysabaan or Alsowl. The plant has its origin in North America and is considered an important natural tree due to its characteristics and numerous environmental advantages. It tolerates the high temperatures in semi-arid and arid areas and endures thirst and dryness as well as air and wind transformations. The plant grows in sandy soils and has endurance for the high saltiness in soil and irrigation waters. Moreover, the mesquite tree is distinguished by its fast and easy spreading, high growth speed and the environmental adaptation with its roots penetrating far into the soil to reach water. In Yemen the common local types are *Prosopis juliflora* Cineraria, which grows in many areas such as Wadi Hajer, Bilhave and Bierali, and *Prosopis juliflora* Farcta, which also grows in North Africa, Pakistan, India and other areas in the Middle East. These types of *Prosopis juliflora* are mostly found in regions up to 1500 m above sea-level with annual rainfall of 150 – 750 mm. They tolerate temperature up to 53Co but they are intolerance to frost. The plants are medium sized and grow up to 15 meters high. The trees grow in different kinds of soil: clayey, sandy or saline soil and in shallow desert areas. They can grow as a tree with one or numerous legs, with a spherical crown or parachutist. The tree leg diameter reaches about 1.5 meters and the wood production is about 75 - 100 ton/ha in a forest (15 - 20 years). Charcoal production is about 3 - 9 m3/ha/year. However, its exceptional growth rate and fast spreading into agricultural lands, marginal lands, wadis, main stream and irrigation channels leads to several problems for the local population and their agricultural production and thus to the fighting and removal of *Prosopis juliflora*. This problem also occurred in several neighboring countries as the Kingdom of Saudi Arabia, Sultanate of Oman and Republic of Sudan, where presently campaigns are organized to stop the invasion and remove 40 million trees.

The official registration of the mesquite plant in Yemen was in 1974, when it was introduced by a FAO project to fight desertification. At this time, local researches started to study its natural and biological characteristics as it was planted in governmental nurseries and was used for fixing the moving sand dunes as

well as for rehabilitation of the arid deserts, both with excellent results. From there, the mesquite tree spread straight ahead in the Yemeni coastal areas into governorates such as Al-hodiadah, Aden, Lahj, Abyan, Shabwah, and Hadramout, additionally increased by animal movements with animals eating and spreading the pods. According to local studies, the area covered by the mesquite tree today is estimated to be 24.000 - 30.000 ha, increasing year by year. One ha of *Prosopis juliflora* contains around 500 trees, each tree producing about 20 kg of pods annually. The ratio of the germination in the nursery arrives to more than 90%. The mesquite tree has become a threat to agricultural crops and soils as it absorbs water from a depth of 30 meter underground and consumes the soil elements. It has the capability to regrow, even if the area is pastured, cut up or burnt.

14.3 Challenges and problems due to mesquite tree invasion

Through invasion of *Prosopis juliflora* (1620 ha) in the Tehama Region the area faces several damages and problems:

- Invasion of wadi channels, flood streams and irrigation channel entrances (aalaabaar), preventing flood water from entering lands irrigated by spate water, changing riverbeds to neighboring villages and cultivated areas, leading to overflow and natural disaster
- Expulsion and displacement of autochthonous local trees and loss of agriculture land and crops
- Deterioration natural pastures
- Agricultural epidemics such as mosquitos, white fly, snakes and other insects, damaging agricultural outputs as well as humans and animals
- Complication and retardation of land preparation due to the tree invasion and thus increase in production and labour costs
- Negative impact on agricultural equipment, vehicles wheels, transportation tools and movement due to the long and poisonous thorns

14.4 Environmental and economic advantages of the mesquite tree

The mesquite tree has the following environmental and economic advantages:

- *Prosopis juliflora* is used for afforestation work, establishing wind buffers and protective belts
- *Prosopis juliflora* is planted near the houses and in gardens to provide shadow for peoples and animals and is a supply of construction material, firewood and charcoal
- *Prosopis juliflora* increases soil fertility from azote fixation and soil texture improvement through tree waste (leaves, flowers, roots, branches) and supports land reclamation, enrichment and fixation of nitrogen in the soil and thus increase of soil fertility
- *Prosopis juliflora* is a source for the production of honey as well as fodder (pods), especially for goats
- *Prosopis juliflora* pods have a good nutritious value as human food (wheat) and animal fodder
- *Prosopis juliflora* creates jobs and employment through cutting of trees, charcoal production etc.

14.5 Management approaches

Optimal exploitation of the mesquite tree requires an integral management with the following elements:

- Good management and condensed organization in a renewed ownership system with specific work plans for land utilization
- Development of a suitable plan for investments in invaded areas, especially for Wadis and main channels near agricultural lands and forest areas
- Establishment of forest research centers and forming specialized administrations
- Encouragement and establishment of suitable industries, using suitable and modern facilities for producing wood, firewood and charcoal
- Attention to the marketing of *Prosopis juliflora* products and awareness of consumers about different products
- Limitation of the exploitation of natural forests, substitution of natural wood by *Prosopis juliflora* wood
- Participation of local communities through work plans and administration of mesquite trees, with specified responsibilities, and exploitation

The aim is to use the benefits provided by the mesquite tree, especially in environmental and economic terms, by avoiding and managing its disadvantages at the same time.

14.6 Suggested solutions to limit the random spreading of *Prosopis juliflora*

The following proposals are possible solutions to limit the random spreading of *Prosopis juliflora*:

- Removal of all mesquite trees from Wadis, irrigation channels and river banks through removal campaigns, using heavy equipment such as bulldozers with extraction of the complete crown and destruction of the sprouts. Avoidance of spreading of seeds with the flood water in the agricultural lands in spate irrigation areas by spreading nets in irrigation channels and burning it in hot oil.
- Removal of trees and shrubs that grow randomly in agricultural land; all small seedlings need to be constantly removed and destroyed manually in early stage, when the removal of the trees is easy. In case of widespread and deep rooted invasion, soil grubbing should be made by using bulldozers and using plowing machines with inverters to abolish all small seedlings covering the land. A constant observation of the cleared land is needed.
- Encouraging poor citizens and their families in the invaded areas to collect and sell the mesquite fruits to specialized authorities processing the fruits into flour and animal food, raising the income level for those poor families and reducing the harm of the spreading seeds.
- One option might also be the control of *Prosopis juliflora* in its flowering stage with trimming of the branches carrying the flowery sprouts.

14.7 Conclusions

The mesquite tree is an important element in afforestation in Yemenite dry and semi-dry areas with an average rainfall of under 50 mm/year and which are not used for agriculture. The plant also provides fire wood and charcoal for local communities in areas where fire wood normally is scarce or natural forests are unsustainably exploited. The tree is also a valuable source of animal fodder and an important location for

honey production. However, its cultivation requires precaution as well as a strong and integrated management to prevent its negative effects and uncontrolled spreading into agricultural lands, wadis and irrigation channels.

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15. Socio-economic impacts of *Prosopis juliflora*-related charcoal trade in Gewane Woreda, Afar Region

Mohammed Datona, Addis Ababa University, Ethiopia

15.1 Introduction

In Ethiopia, fuel wood and charcoal constitute the most important sources of energy for both rural and urban households. A wood energy survey of 1996/97 (EC) indicates that 230,000 tons of charcoal is used every year in the country. According to the Ethiopian Forestry Action Program (2011), fuel wood including charcoal contributes 66 and 62 percent, of the energy consumption in rural and urban areas respectively. Charcoal production is a major threat to biodiversity because it eliminates indigenous species found in natural forests and accelerates deforestation.

In pastoral areas of Afar Region charcoal production is a rather new phenomenon. One of the main production sites currently is the Baadu area (Gewane and Buremodaytou Woreda), a floodplain with abundant grasses and few acacia forests in the past, located within the Middle Awash Basin. This area has been almost completely invaded by *Prosopis juliflora* within the last three decades so that pastoralists lost valuable dry season grazing areas along the Awash River. In a context of dwindling fodder resources people are under pressure to develop new complementary non-pastoral livelihood strategies and to adapt to the changing environment. It is argued that charcoal production and sale in Baadu is such a new livelihood strategy but which involves not only benefits but also serious social and ecological costs.

In a case study in Gewane wereda the socioeconomic impacts of *Prosopis juliflora* related to the production and trade of charcoal were analyzed. The case study was part of a social impact assessment implemented by the University of Bonn, in cooperation with GIZ and the University of Bayreuth. The main objective of the study was to investigate the socio-economic impacts of charcoal production. Questions addressed were: How is the production of charcoal organized and which actors are involved? What are the socially differentiated positive and negative impacts of charcoal production on local livelihoods? What is the role of the government in regulating the use of forest products for charcoal production?

Methods applied during 6 weeks of field work around Gewane included a quantitative survey on household level as well as qualitative interviews with key informants and focus group discussions. Observation methods played an important role during field trips, e.g. in cross-checking the amount of the currently illegal cutting of *Prosopis juliflora* and indigenous trees within the area and of the marketing chain of charcoal contraband trade.

15.2 The history of charcoal production in the Baadu area

The production of charcoal was introduced to Gewane woreda in 2003 by the British NGO FARM Africa in order to make use of the many areas invaded by *Prosopis juliflora*. The NGO mobilized and assisted local communities in clearing invaded lands from *Prosopis juliflora* in order to generate income through the use of the cleared land for crop production and the *Prosopis juliflora* wood for charcoal. Since the introduction by FARM Africa a rapid growth of the charcoal business took place in the area but local communities turned their attention increasingly towards the production of charcoal from indigenous trees after they had realized the difference in terms of demand and market price between charcoal made of *Prosopis juliflora* and of indigenous trees such as acacia. Therefore, after a two year legalization of charcoal trade, the business was banned again in 2006. Since then it is performed as an unregulated contraband business causing many ecological and social problems.

Production sites of charcoal shifted significantly within the last 10 years. The production sites first focused on the oldest and largest *Prosopis juliflora* forests around the old, now abandoned state farm near Biida Foro (Buremodaytou Woreda) where trees reached heights of about 10m. After these forests were increasingly cut and access became difficult due to floodwaters from the Awash River, the charcoal business moved to areas north of Gewane (Fig.1) where *Prosopis juliflora* as well as few remaining forests of indigenous trees in Baadu could be found.

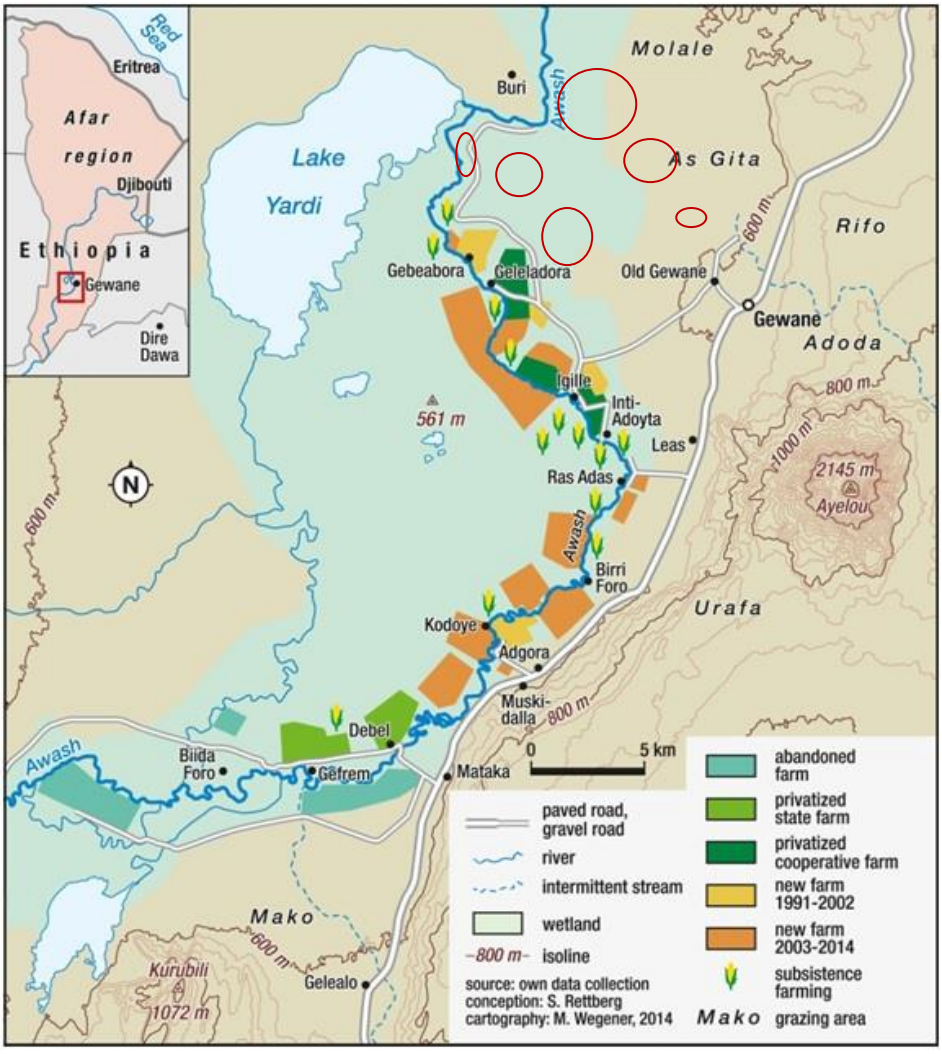

Figure 1: Current main production sites of charcoal in Baadu (⬭)

One Afar elder remembers the value of the forest that existed in the past:

"Between Birri Foro and Galaeladora there was no tree to cut at all. It was all plain grassland. The only place with trees was from Kada Baada to Butakonta and from Orro down to Aswaloyta (near Galaeladora/Gebeabora). It is that forest camels liked to stay inside. One can't recognize that forest anymore because the Woyane tree covered everything. The tree just outnumbered all other trees and destroyed that forest. ... People came from Alta when there is threat of Issa, this forest used to be their refuge. Nothing touches the animals there, it is safe for them, camels give birth... When we had that forest our animals used to benefit from it. Camels used to feed on them. It used to provide food for our animals, it used to provide us with shade." (2005)

All these benefits for pastoralists are not there anymore, partly due to the replacement of indigenous trees by *Prosopis juliflora* and partly due to deforestation for charcoal production.

15.3 Organization of trade and actors involved

The main actors involved in the charcoal trade within Afar can be classified into three groups: charcoal owners, charcoal producers and the local Afar communities (Fig.2).

The charcoal owners are the major actors in the chain who own the produced charcoal and control the production process. These are mostly highlanders as well as young, partly educated Afar men who employ charcoal makers for the production of charcoal in the forest, including the cutting of the trees, the process of processing of the woods in earthmound kilns and the packing of charcoal in bags. During the production process deep inside the forested areas the owners provide the workers with food and finally the workers get paid ETB 20 for a 50 kg bag of charcoal (Fig.3/4).

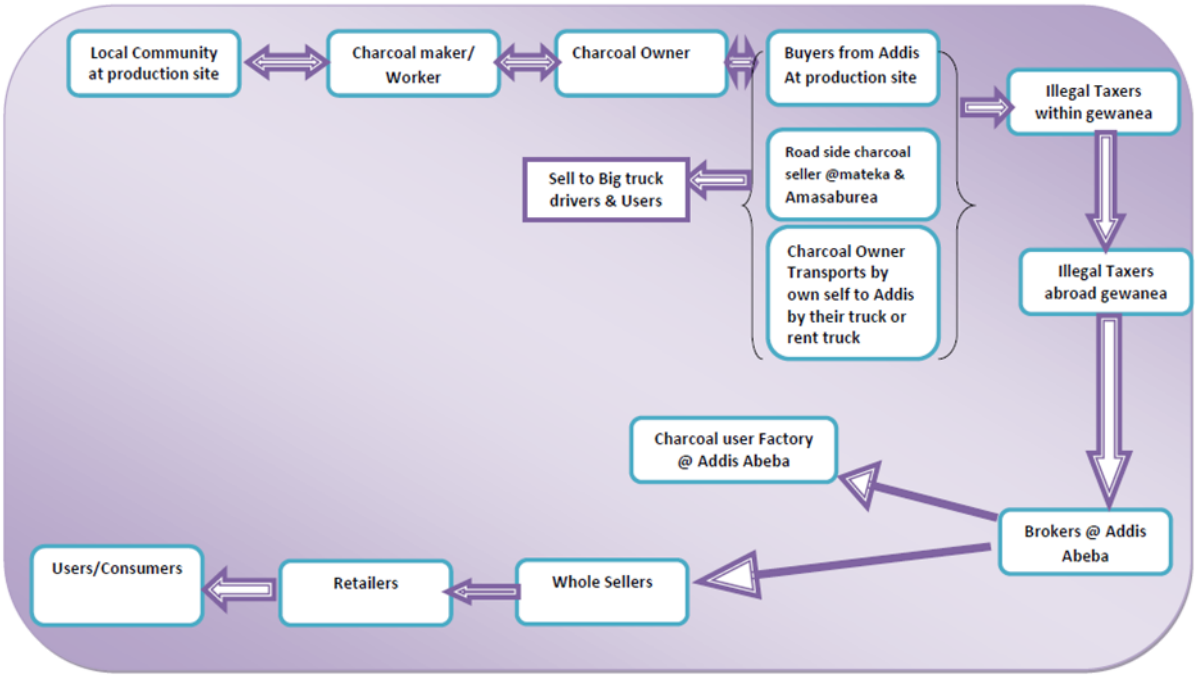

Figure 2: The charcoal commodity chain in Baadu, Afar Region (own draft 2014)

The charcoal is then sold by the owners in three different ways:

- Directly to buyers from Addis at the production site (no transport costs)
- To nearby charcoal sellers along the Djibouti-Addis Ababa road
- Directly to brokers in Addis Ababa (transport with own or rent Isuzu)

Figure 3: Charcoal bags waiting to be picked up by ISUZU truck (DATONA, 2014)

Figure 4: Charcoal workers with tools and food items (Datona, 2014)

Charcoal owners have to make an agreement with local communities for the security of the non-Afar charcoal makers who are mostly migrant workers originating from the neighboring highland regions of Southern Nations Nationalities and Peoples Region, Oromia and Amhara Region. In order to protect them the owners employ small numbers of young Afar men from the community as guards (one guard protects around 10 workers). For each protected worker the young Afar get a payment of 300 ETB but the vast majority of Afar pastoralists and agro-pastoralists who live in the area of the production sites are not involved

in the charcoal business. Another way how Afar youngsters benefit indirectly from charcoal trade is through illegal taxing along minor roads inside Baadu. Isuzus loaded with charcoal and travelling to Gewane town get stopped at certain checkpoints which indicate clan boundaries where they have to pay between 50-200 ETB.

The prices for one bag of charcoal (50kg usually) made of *Prosopis juliflora* differ between the production site, the roadside, and the destination site in Addis Abeba. The average price at the production site was found to be ETB 60, ETB 80 at the road site and ETB 120 in Addis Ababa. Charcoal is transported to the markets in Addis Abeba by ISUZU truck. One truck can carry around 270 bags of charcoal.

15.4 Costs and Benefits of charcoal trade

During the case study different forms of conflict among stakeholders were observed. On one hand, conflicts exist between charcoal owners and charcoal producers (Fig.1). On the other hand conflicts between clans, charcoal makers and the local communities were observed. Other impacts which can be connected to the production of charcoal around Gewane are increasing incidents of rape cases with subsequent killing of women by charcoal producers. People also reported that the thickets of *Prosopis juliflora* offer shelter to wild animals like lions. The number of wild animals is increasing and it was reported that many charcoal makers were killed by lions around the charcoal productions sites.

The monitarization of the society caused by the possibility to generate high income from the charcoal business has led to a change of values in the society. While reciprocity and sharing are traditionally highly valued among pastoralists, nowadays there are growing individual interests especially among the young generation to generate exclusive high profits. This is linked to a growing trend among some youngsters to distance them from the traditional pastoralist life. Natural Resource Management institutions were weakened in the process and traditional law of the Afar, the Afar Madaa, which prohibits the cutting of indigenous trees, is less and less respected.

Due to the illegality of the charcoal trade, corruption has become a main problem in the region. Illegal taxing has become a major issue on the main road going to Addis. Before the charcoal is finally sold to the brokers in Addis several checkpoints have to be passed. Large amounts of money have to be paid to customs officers there in order to avoid the normal inspections. Only in 2013 several high ranking officials of the Ethiopian Revenues and Customs Authority (ERCA) were charged for corruption. Therefore, the illegality of the trade prevents the Woredas from significant tax incomes. Based on documentation of tax incomes from the time when charcoal was a legal business, it can be estimated that currently 60,000-80,000 Birr per day are lost as tax income.

In terms of ecological impacts the cutting of indigenous trees (Fig.5) has disastrous effects on local biodiversity and livelihoods. Charcoal produced from indigenous trees is of higher quality so that the demand for charcoal made from indigenous trees is very high compared to charcoal produced from *Prosopis juliflora*. The preference of indigenous trees as source for charcoal instead of *Prosopis juliflora* together with the unwillingness to be assigned in groups in order to prevent illegal removal is accelerating the eradication of indigenous species in the Gewane. 40% of the surveyed households prefer to prepare charcoal from indigenous tree species. The survey showed that these people are willing to form an association, on the one hand hoping to secure their future business and on the other hand to contribute to the protection of indigenous trees from being cut.

Figure 5: River side deforestation of indigenous trees for charcoal production (DATONA, 2014)

The main benefits of the charcoal business are going to charcoal owners and their families. Their income can cover for expenditures like school expenses, medical expenses, as well as covering the expense for buying chat. The income is also used to pay for food items, to build houses and to buy ISUZU trucks and/or motorbikes (Fig.6). Some of the charcoal owners save some of their income to invest in agriculture. Still, the majority of the Afar are left empty-handed except for the guards who get small income for the protection of the workers and the Afar who started to tax the Isuzus on the way to Gewane (Fig.7). More important for the large part of the community is the improved access to local transport since nowadays many Isuzus and motorbikes are available in the area.

Figure 6: Motorbike in front of *Prosopis juliflora* (DATONA, 2014)

Figure 7: Checkpoint for illegal tax collection in Baadu (Datona, 2014)

15.5 Aspects of governmental rules and regulations

The regional government of Afar has developed clear rules and regulations against *Prosopis juliflora*. Rules, regulations and proclamations were approved on 7th July 2011 on a regional level. This paper was put into place to organize the control, management, and eradication of *Prosopis juliflora*. The proclamation further justified that the plant is thorny, it is causing considerable physical damage to human being and animals thereby forcing pastoralist to leave their normal grazing lands. These rules allow pastoral communities to produce and sell charcoal made from *Prosopis juliflora*. However, the existing rules and regulations have never been applied. The lack of political commitment to implement the policy is partly due to the involvement of some politicians into the trade. The lucrative profits that have changed the livelihood of those involved in the business also attracted local officials who became partly beneficiaries.

15.6 Conclusions and the way forward

The paper outlined the organization of the fast growing charcoal business in the Gewane woreda and its impacts on an economic, ecological and social dimension. The main actors in the charcoal value chain can be identified as the charcoal owners, the charcoal makers and the sellers of charcoal. Work tasks are shared between the Afar living in the area and the highlanders who are coming from different regions of Ethiopia in search for work.

The results reveal that the benefits obtained from charcoal production from *Prosopis juliflora* attracted the interest of local communities, especially in a context of increasing impoverishment of pastoralists. But the current form of unregulated charcoal business is ambivalent: it improves the livelihood of some significantly, but at the expense of deforestation and desertification. As time goes on, the illegal cutting of indigenous trees has reached an alarming stage demanding to study the extents of damages to indigenous trees, especially Acacia. As the severity of the problem is known and this is clearly revealed in this study, it is suggested that the regional and local government officials directly responsible for the problem has to act soon by taking action on charcoal makers and owners for cutting and selling charcoal from trees other than *Prosopis juliflora*.

Besides, the government officials at all levels of administration do need to discharge their political commitment in close consultation with the local communities in ensuring the aggressive removal of indigenous tree before their complete destruction.

The following recommendations should be considered for a socially and ecologically sound and sustainable charcoal trade:

- The local government should legalize charcoal trade from *Prosopis juliflora* and facilitate distribution of trade licenses to individuals so as to prevent indigenous tree distraction.
- Increase of wood supply through agro-forestry in farming areas by introducing village woodlots. The depletion of forest resources due to charcoal production is the most serious environmental issue in the country.
- Awareness raising on resource management and empowering communities to take the responsibility of protecting the environment and enhancing and helping local institutions is a key factor that will contribute for slowing down the current rate of deforestation.
- The government should place more emphasis on managing land in collaboration with the local people. The participation of local communities in the interventions and decisions that will have impact on them is crucial for creating a sense of ownership and sustainability. An aspect of this management might be that charcoal to be burned only by people with permits in specified areas, but this is not realistic, currently as charcoal production has become a widespread occupation among pastoral communities.

16. *Prosopis juliflora*, Parthenium and beyond, challenges for an integrated strategy of IAS control in the Afar Region

Wondimagegne Chekol, Saint Mary's University, Ethiopia
Irmfried Neumann, Consultant, Germany

16.1 Introduction

Prosopis juliflora L. (hereafter referred to as *Prosopis juliflora*) is considered being the economically most damaging species amongst the 35 which are listed as IAS in Ethiopia (FESSEHAIE, 2014). Therefore, *Prosopis juliflora* receives particular attention by the authorities and research and development actors. Specific programmes for the control and management of *Prosopis juliflora* in the Afar lowlands started back in the years 2000 by Farm Africa (FARMAFRICA, 2008). Based on these early experiences, the government of the Regional National State of Afar proclaimed a regulation issued to control, manage and eradicate the invasion of *Prosopis juliflora* (ANRS, 2011), which describes the control strategy and provides institutions with the necessary mandate. The regulation still waits for its implementation as means provided are limited. While *Prosopis juliflora* is currently high on the agenda of development actors, other IAS relevant for the Afar Region like Parthenium hysterophorus and Acacia nubica (hereafter referred to as Parthenium and Acacia) receive relatively little attention. The organisers of this Conference on *Prosopis juliflora* therefore invited this paper to widen the outlook on IAS control as a whole. On the one hand this allows to remind interested actors that the Project, "Removing Barriers to Invasive Plant Management in Africa", articulated a comprehensive proposal for a "National Invasive Alien Species Strategy and Action Plan of Ethiopia" (EIAR 2010), which is based on an extensive analysis of IAS in the country und proposes the necessary measures for their control. The application of the proposed national strategy and action plan would make the control and management of *Prosopis juliflora* part of an overall IAS-strategy and avoid isolated solutions which might lead to duplication of programmes and institutional structures. The federal government is about to prepare new regulations for IAS control (State Minister of Lifestock, 2014) which might take some time to become operational. On the other hand, no time should be lost and action taken to start the work of controlling IAS in the Afar-region and elsewhere. For every year of inactivity the price to be paid by local communities and the government will be considerably higher. A number of development actors are prepared to intervene instantly.

In order to prevent isolated and non-sustainable activities an intermediate strategy for a coordinated action is proposed in this article. The article gives a short account of Parthenium and Acacia in the Afar lowlands in order to illustrate the new challenges of IAS as examples for the necessity to address all invaders under one integrated strategy. The paper emanated from a preliminary study in the Afar Region which prepares practical interventions of improved land use.

Figure 1: Irrigation plot overgrown with *P. hysterophorus*.

16.2 Important invaders in the lowlands

In the absence of recent surveys on the current status spread of IAS to the Afar Region, information of key-informants (Fessehaie, pers. comm., 2014) and own observations are the base of the following list of species:

- Acacia nubica (Geronto)
- Calotropis procera (Sodom Apple)
- Cryptostegia grandiflora (Rubber Vine)
- Nicotiana glauca (Tree Tobacco)
- Parthenium hysterophorus (Democracy or Congress Grass)
- *Prosopis juliflora* (Mesquite)
- Senna didimobotrya (Peanut Butter Cassia)
- Senna occidentalis (Senna Coffee)
- Xanthium strumarium

Prosopis juliflora is by far the most widespread and economically important invader in the Afar Region (Fufa, 2010). It forms large mono-specific plant populations which suppress other species. Large stands of IAS have also been observed with Acacia and Parthenium in Afar whereas other invading species are mainly found along road embankments, in linear patterns along paths, animal trails and waterways.

16.3 Parthenium

The impacts on biodiversity, animal and human health of Parthenium in Afar are not fully documented. However, primary studies on pastoral and agro-pastorals' perception in Afar and in other parts of Ethiopia indicate that Parthenium is an environmental weed which causes irreversible habitat changes in native grasslands, woodlands, river banks and floodplains. It is reported from several authors that Parthenium occurrence in range land or grazing land reduces forage products up to 90% by suppressing and replacing the natural vegetation due its allelopathic potential and thus becoming an enormous threat to the biodiversity in Afar Regional State.

According to Fufa (2010) on the perception of farmers on the effect of Parthenium it causes allergic and skin irritation, fatigues, headaches and fever when people weed the plant with their hands. From the same study on its effect on livestock, farmers reported that it has a direct or indirect effect on animals by affecting grazing land, animal health, milk and meat quality, and marketing animal products. Studies on Parthenium effect on crop reveals that it affects crops by exerting strong allelopathic toxins which reduces the growth and reproduction of associated crops (Taye T. et al & Taye Tessema, 2009). It is also reported that 40-97% sorghum (Sorghum bicolor L.) yield reduction is caused due to Parthenium in Ethiopia depending on the year and site, if Parthenium is left uncontrolled throughout the cropping season.

In regular farming there are little problems in managing Parthenium as land is regularly tilled and weeds mechanically controlled. Whereas in low intensity farming, where there is no regular ploughing and weed control Parthenium can become a big problem and entirely cover farmland outcompeting other species (see figure 2).

Along irrigation channels the only option is to hand weed. If not weeded it becomes a source of re-infestation. On rangeland all options to work with labour intensive methods would have little chance to succeed, seen the large extend of the areas and the cost in relation to the returns of livestock production. There are proposals to work with area enclosures, removing mechanically Parthenium and sowing competitive improved varieties of fodder grass. These options need more research under lowland-conditions.

Ongoing research at EIAR gives hope that biological control mechanisms will contribute to controlling Parthenium.

Figure 2: Acacia nubica invading rangeland in Afar Region (Nov. 2013)

16.4 Acacia nubica

There are doubts whether Acacia nubica can be considered an exotic species to the Afar Region. But it has recently developed an aggressive dynamic of spreading on rangeland. It therefore can be considered as an invasive species that needs to be controlled.

One major infested area can be found between on the alluvial plain between Awra and Ewa along the road (Kebele of1stBatoli and Ewa Woreda), where it is estimated to cover 5 to 10 km² (April 2014) and outcompeted widely other species. Only few indigenous trees survived the invasion. There were only marginal remnants of grass sods under and between the Acacia shrubs.

The local communities, who call the species 'Geronto' in their local language, describe the invasion as a major loss of productive rangeland as fodder species do not grow amidst Acacia. People living in the area started clearing Acacia around their homesteads by pulling the plant out by its roots. They stated that this method prevented the plant from regenerating and growing back (Pearson, 2013). According to them, clearing through burning failed. This might be due to the thin branches and low above ground biomass of Acacia shrubs. Mechanical removal of large stands of Acacia on rangeland seemed to be too labour demanding. Hence, the communities resigned from clearing the Acacia thickets. Another problem cited was that Geronto thickets provided shelter for hyenas and other scavenger animals. Around some homesteads, Acacia was used for fencing.

16.5 IAS in the Afar Region– summary of findings

From a development actor's view, this preliminary study allows for the following conclusions: Besides the massive problem created by the *Prosopis juliflora* invasion in the Afar Region, Parthenium and Acacia are now firmly established in some Afar areas and spreading on rangeland and irrigation plots. The pastoral communities are not able to cope with the demanding task of controlling IAS, particularly on rangeland.

There is no up-to-date survey on the real spread of IAS and their economic impact in the Afar Region. So, regional and national authorities and institutions have no precise picture of the current situation and the impacts.

Local communities have a clear perception of the impact of Parthenium and Acacia on their land and livelihoods. Their spread resulted in loss of crop harvest and fodder resources and, in the case of Acacia, of access to the land and mobility for their herds. They express their concern and deplore their lack of means to encounter the invasion.

There are no experiences how to manage and rehabilitate Acacia- infested pasture land.

Invasion of irrigated land by Parthenium is more easily addressed by agro-pastoralists. But there is little preparedness to eradicate the plant along the irrigation channels, pathways and in settlement areas. Pastoralists have no means of controlling Parthenium spread on rangeland

Development programmes and local communities are in a "reactive" mode concerning the appearance of a new IAS. Only when an IAS species is established and starts causing tangible problems, the menace is realised. Preventive measures in terms of early detection and organised rapid response through eradication are not possible in this way and the halting of further spread of IAS to non-infested areas in the region not possible..

Local and regional institutions are not sufficiently equipped to provide communities and development organisations with the necessary support for action.

In the meantime the spread of IAS is going on. The need for starting coordinated action with a long-term perspective which covers the whole area of Afar Region is crucial.

16.6 Towards an intermediate strategy for instant action

On federal level, the Ministry of Agriculture has started activities (like the consultation with partners on the Rangeland Management Platform) that are likely to lead to the creation of a national policy, strategy and action plan on IAS management. EIAR prepared an extensive proposal for such policy development. The urgency of the situation puts development actors into the difficulty to instantly act yet not having the full framework for effective and sustainable action of the new IAS-policy, which would help to avoid the risks of isolated activities without sustainable impact. The following list of activities sketch a proposal on how to prepare for an instant response to IAS threats in Afar, while maintaining the potential to integrate into a future national policy set-up.

Management and coordination on different levels of the region

Create coordination platforms (working groups or committees) of stakeholders on different levels under the guidance of the Bureau of Pastoral and Agro-Pastoral Development of Afar Region (BoPAD, 2014) which should be supported by development partners in this task (starting with regional, then Woredas and Kebeles, - see ARNS proclamation on *Prosopis juliflora*).

- Based on survey results (see below), have strategic reflections with all stakeholders on how to tackle the threat by defining priority areas, action plans and necessary means for implementation on the scale of the region.
- Bring development partners and administration together for financing of activities.
- Information exchange, planning and coordination of activities of all development actors including representatives of local communities with IAS activities.

Update state of knowledge on the spread and economic impacts of IAS in the Afar Region

- The first step for developing an intermediate management strategy is the design and implementation of an IAS-survey for the region (building on methodological know-how of EIAR and other research institutions, implementation of survey preferentially integrating institutions from the Afar Region like Afar Pastoral and Agro-pastoral Research Institute (APARI) and/or University of Samara). The survey should cover the whole region and allow analysing pathways of IAS spreading and of impacts.
- Surveys should include a risk analysis of invasion of IAS from outside the region (early detection of new IAS, forecast of spreading patterns of newly arriving IAS and of IAS already existing in some areas of the region to those not infested).
- Organise trainings for management staff and local leaders on relevant aspects of IAS spread and related hazards in the region as well as approaches to manage the invasion.

IAS control and management measures, research and land use planning

- On Kebele level, bring together local community representatives and development actors to define economically attractive and socially feasible land use plans for land to be cleared from IAS (including *Prosopis juliflora* charcoal production and trading).
- Together with land-users, identify technical approaches to clearing and rehabilitating infested land for every IAS including measures against re-infestation.
- Identify those situations where more research is needed for developing IAS management and land use alternatives. Where ever possible and meaningful, carry out this research together with the land users. Document and share results on local and regional levels.

- Prevention of invasion through awareness creation: create effective instruments for information and training of communities and the local administration. Have regular local information events on the current evolution in the area and about potential invaders.
- Create local groups of land users (and residents of settlements) who have the mandate to detect and eradicate new IAS. Organise their training and support.

How to proceed on institutional level

- Where ever possible, activities of IAS management and land use planning and implementation should be carried out in cooperation with institutions (also customary ones) that are or will likely be mandated with specific responsibilities related to IAS under the forthcoming policy. This should be done in a way which strengthens capacities of these institutions and their personnel.
- Creation of a working group/committee on regional level, informing the regional council and supporting BoPAD to carry out coordination and monitoring task of activities on regional and woredas levels (also reporting back to federal level).
- This organisational entity should also be able to monitor impact of actions taken and come up with related recommendations for policy implementation on the regional and national level.
- Mandating and equipping a regional institution to create a permanent "IAS-observatory" carrying out surveys on IAS spread in regular intervals and monitoring effects of IAS control measures and keeping actors informed about necessary prevention measures for every given Woreda.
- Creation or strengthening of IAS-committees/working groups on Woreda, Kebele and local level to carry out the works related to IAS and implementation of new land use plans.

Preparing an integrated strategy

Long term success of IAS control will largely depend on developing pastoral and agro-pastoral land use practices which are highly attractive to the local communities. Only the perspective of solid economic gains will mobilise sufficient motivation in local communities to engage in the tedious tasks of managing and preventing the spread of IAS. Hence, IAS-management has to be incorporated in an integrated strategy which takes in account social and economic differences of communities. The pastoral and agro-pastoral Afar communities are currently undergoing an economic and socio-cultural transformation process which needs adaptation of development strategies to local differences. Experimenting and elaborating livelihood strategies together with the different communities while taking into account gender related interests is a promising way to get into grip with the challenges ahead. Authorities and development partners should be prepared to accompany these transformation processes of local communities with a long-term commitment. Otherwise alien invasive species will drive the process of transforming local societies as well as the natural habitat in the Afar Region at an even higher cost.

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17. Minutes of the Discussions during the Regional Conference on Invasive Species in ASAL

17.1 Introduction

The regional conference was resumed by forwarding welcoming address via the Academic vice president of Mekelle University, Dr. Abdulkadir Kedir and the Counselor for Development Cooperation from the Embassy of the Federal Republic of Germany - Fritz Jung. Following the welcoming address note, workshop organizing institutions GIZ, UNESCO-IHE, Mekelle University, and MetaMeta had the chance to introduce themselves. Then opening remarks were forwarded by the State Minster for Natural Resources and Livestock Management of the Ministry of Agriculture and Rural Development Mr. G/egziabher G/yohaness. Finally, the participants were systematically grouped to introduce their organizations, explain why they are attending the conference and to express what their expectations are.

The conference presentations can be downloaded here:

www.agriwaterpedia.info > Agricultural Water Management > Invasive Alien Species > Regional Conference on Managing *Prosopis juliflora*

http://agriwaterpedia.info/wiki/Regional_Conference_on_Managing_*Prosopisjuliflora*_Juliflora_for_better_(agro-)pastoral_Livelihoods_in_the_Horn_of_Africa

17.2 Discussion

Day #1

Presentation 1
The presentation was made by Simone Rettberg from the University of Bonn which is entitled "History of *Prosopis juliflora* spread in Baadu, Ethiopia from a socio-ecological perspective".

Research undertaken by the presenter has shown that the area under *Prosopis juliflora* by the year 2000 was 8%, and in 2010 it reached 30%, and in 2013 its coverage is around 40% in which the affected dryland vegetation has increased by fivefold. It has also shown an increased pastoral vulnerability in terms of: Loss of dry season grazing along the Awash River, Exposure to wild animals, constrained access to water points, new animal diseases like Harmaku, and Increased incidences of Malaria.

The impacts can be categorized as:

- **Socio-political impacts include:** So far only few benefit from use of *Prosopis juliflora*, weakened social capital and contested land rights and conflicts between Afar clans.
- **Ecological impacts include:** Widespread deforestation and destruction of riverine forests, further degradation of wetlands, Salinification and water pollution and Creation of new risks for pastoralists.

Presentation 2
The presentation was made by Abeje Eshete which is entitled "Ecological challenges and potential carbon storage benefits of *Prosopis juliflora* in Afar".

This presentation is the result of a fundamental and practical research undertaken on understanding the ecological impacts of *Prosopis juliflora*. The study undertaken by the presenters shows that,

- there is a positive impact of *Prosopis juliflora* on the soil parameters (i.e., organic matter) which can be used to rehabilitate degraded lands in a controlled manner.
- *Prosopis juliflora* invasion success seems to be supported by presence of mycorrhizae (though so far only the spore abundance is known).
- *Prosopis juliflora* growth has negative effect on other woody species (low browsing quality).
- enhanced biomass and Carbon stocks can be positive in terms of climate change mitigation (microclimate, soil moisture content, organic matter, C trade, alternative income generation).
- it is still not too late for rehabilitation as there is good quality soil and high regeneration potential of native species as shown in soil seed bank.
- investigation of genetic diversity needed to look for varieties/hybrids with less invasion characteristics.
- current management might not be sufficient /rather encouraging.

Presentation 3
The Presentation was made by John Ilukor which is entitled "Total Economic Value of *Prosopis juliflora* Invasion: An economic assessment of the impact of *Prosopis juliflora* invasion and participative management approaches in Afar Region, Ethiopia".

This study has tried to estimate the costs and benefits of *Prosopis juliflora*. The study has estimated Benefits of 4.4 billion Birr and costs of 2.2 billion Birr in the whole Afar Region.

Presentation 4
The presentation was made by Mesfin Tilahun which is entitled "Households' demand for mitigation of *Prosopis juliflora* invasion in the Afar Region of Ethiopia: a contingent valuation".

The main objective of this study was to assess households' demand for mitigating *Prosopis juliflora* invasion either in "complete eradication" or "controlling expansion through productive use" and amounts and determination of households to contribute either in the form of cash or labour. The study revealed that,

the Afar people are willing to pay and have high interest on eradicating *Prosopis juliflora*. But, after eradication land should not be left empty (it has to be replaced with other plant species).

Questions rose for the four presentations listed above

Q1: *Even though Prosopis juliflora has a negative impact on other species, carbon fixing is one of its good advantages. So can carbon trading be recommended in areas like Afar?*

A1: It depends on how you manage the land considering the negative and positive impacts. Carbon trading is worthy as its cost is only 6 USD/yr but its benefit is worthy. But, with complete eradication and replacing it with other species plants also helps in carbon fixing.

Q2*: If the people are willing to pay and there is good policy, what is lacking in mitigating Prosopis juliflora?*

A2: What are lacking are: institutions that innovatively operate and adapt need to be established. Furthermore, free riding of animals is causing a lot of problems.

Q3: *Why was it introduced? And has its objective been attained?*

A3: *Prosopis juliflora* was introduced in 1970s to combat desertification and soil erosion through afforestation. But, it is an invasive tree replacing herbaceous trees and native grasses as it has good quality for mitigating climate change impacts through its higher capacity and ability to grow and survive in worst areas. It also claims croplands and incurs more labor for land clearing. Pastoralists are cutting it to control, but cutting is encouraging it to expand and invade.

Q4: *Complete eradication is suggested and preferred by the pastoralists, is it possible as the seeds can stay alive for 20 years and more?*

A4: *Prosopis juliflora* has completely transformed the livelihood of the pastoralists. A Farmer attending the conference has witnessed that, before its arrival 80 grass species were growing but now majority of them have vanished by the colonization of *Prosopis juliflora*. Currently, the area invaded by *Prosopis juliflora* is around 1.5 Million ha and its annual rate of invasion is around 50,000 ha/year. It is also upsetting both human and animals health through physical injuries, adversely affecting the biodiversity of the area, forcing towards land use changes and conflicts on land. But, either complete eradication or should benefit the pastoralists.

Presentation 5
The presentation was made by Mohammed Jemaneh which is entitled “Household perception about *Prosopis juliflora* and its effect on Pastoral livelihood diversification strategy”.

The main objective of this study was, to assess the determinants of livelihood diversification strategies of pastoralists, to identify factors affecting community perception concerning *Prosopis juliflora* and assess the effect of pastoralists’ perception regarding *Prosopis juliflora* on their livelihood diversification strategies. Results of descriptive analysis showed that household perception about *Prosopis juliflora* accounted 50.7% unlikely perceive, 24% neutral and 25.3% likely perceive.

Presentation 6
The presentation was made by Helena Inkermann which is entitled “Gender aspects of *Prosopis juliflora* spread, perceptions, impacts and coping strategies”.

The study has identified that, Men and women perceive invasion mainly in the same way as it is a threat for livestock in particular and food security in general. But, pastoralist women are more vulnerable than men. The copping strategies are changing the power relations and empowering women through diversifying their *Prosopis juliflora* income sources.

Presentation 7
The presentation was made by Hamisi Said Nzumira which is entitled "Mesquite tree infestation on Gash spate irrigation system: Impacts and remedial measures".

The study reveals that, Mesquite tree was introduced in 1917 in northern and eastern parts of Sudan for the purposes of dune stabilization and it is estimated that, over 142,000 ha of irrigable land is infested.

Questions rose for the three presentations (Presentation 5 to 7)

Q5: *Suppose there is cash for work what arrangements can be made for motivating pastoralists and how should women actually work with men so that the joint work is productive?*

A5: It is possible for men and women to work together. The experience from Yemen can be seen as a good example where women are involved in crashing seeds which are used as a feed for honey bee.

Q6: *What is the role of children in the Afar system and how do you see the role of woman in relation to the clan arrangements?*

A6: Children go with goat at the age of eight. Women are responsible for in house management. Women do not travel with animals as they are not protected against sexual harassments.

Q7*: What kind of institutional arrangements exist in Gash scheme?*

A7: In Sudan there is no good leadership as most of the spate irrigation farmers are nomads. In 2008 the Sudanese government launched *Prosopis juliflora* eradication program and contracted to private contractors but instead of eradicating *Prosopis juliflora* is infesting vast land. Nowadays, the GASA (Gash Agricultural Scheme Authority) is contracting 5 ha of area for eradication by individual farmers.

Q8*: Pastoralists are not directly involved in producing charcoal from Prosopis juliflora as they do not have tools used for producing. If we give them advanced tools, how is it going to help?*

A8: Pastoralists need input materials and capital which is one of the limiting factors. Hence, if they are given the necessary input materials and capital, it will make them the direct beneficiaries.

Summary of Ministry of Livestock's Rangeland Management Platform Meeting on Prosopis juliflora, which was held on 16th April 2014 by Fiona Flintan

It was discussed and forwarded is that, *Prosopis juliflora* is one of many rangeland issues that require incorporation into planning processes at different levels - mainstream *Prosopis juliflora* (invasives) into national, regional and local development and land use planning processes e.g. proposed National Land Use Plan and PRM. Different situation require different interventions – rational decision making and priority setting. Furthermore, Nation-wide long-term strategic action needs to be taken to address the *Prosopis juliflora* problem. This should focus on control (based on a vision of eradication) – utilizing biomass as it is removed.

Day # 2

Presentation 8

The presentation was made by Frank Van Steenbergen which is entitled "*Prosopis juliflora* in Spate Irrigation Systems: Control and use of *Prosopis juliflora* in Sudan, Yemen, Ethiopia, Eritrea and Pakistan".

The study showed that, there are four *Prosopis juliflora* controlling and management techniques namely, biological, burning, mechanical and chemical. It also recommends that, a combination of the above listed four techniques is the best approach to control and manage *Prosopis juliflora* and should ensure the use of the eradicated/uprooted trees. It also summarizes the positive and negative impacts of *Prosopis juliflora*.

Positive impacts	**Negative impacts**
Can play a role in sustaining the livelihood of poor rural households	Lack of traditional knowledge on how to manage and control the plants
Source of fuel and dry season animal feed	Obstructs paths and roads
Wood does not spit, spark or smoke excessively (produces good charcoal)	Hard and costly to remove
High quality and hard timber (can be processed into furniture or construction material)	Expands quickly even in the hardest conditions
Good animal feed	Thorns can injure animals and people
Can act as vegetative fencing to delimit and protect properties	Depletes the water moisture and groundwater
	Few plants are able to grow under its crown shade
	Can favor the breeding of malaria by spreading mosquitoes
	Causes pastoralists communal lands to shrink

Presentation 9

The presentation was made by Wondimagegne Checkol which is entitled "Experiences of EIAR in *Prosopis juliflora* management and Control in Afar".

Presentation 10

The presentation was made by Simon Choge which is entitled "Management, control and utilization of *Prosopis juliflora*: Global experiences that informed approaches for Kenya".
The presentation summarizes the approach used in Kenya.

- Awareness creation and defining the problem (1999- 2004)
- Participatory development of technologies on management and control (silvicultural, biological, etc.) (2005- 2008)
- Strengthening of capabilities of communities to manage the invasions (2009 to date)
- Focus on invasionmanagement through resource processing and utilization (on-going)
- Formation of community structures for effective management and linking industies to the *Prosopis juliflora* resource (on-going)
- Commercialization and refining processing and marketing structures, developing Research and Development (R&D) blueprint (on-going)
- Seeking other alternative sources of income from *Prosopis juliflora* resources (carbon trading) and improving marketing (pilot certification of charcoal)

It discusses about the *Prosopis juliflora* situation in Peru, Argentina and India where *Prosopis juliflora* pallida, *Prosopis juliflora* kuntzei, *Prosopis juliflora* alba and *Prosopis juliflora* ruscifolia are big assets. It also discusses the experience of Australia, South Africa, Sudan and Kenya in controlling and managing *Prosopis juliflora*.

Questions rose for the three presentations (Presentation 8 to 10)

Q*9: What benefits does charcoal biomass have?*

A9: It improves the productivity of the soil by enhancing bacteria growth.

Q10*: What is the role of Kenyan government towards the control of Prosopis juliflora?*

A10: It allocates annual budget estimated 5 million Dollar. Research institutes are also mandated to undertake research (on species that have infested and negative impact on the environment) and development works. The research institute is working on controlling the invasion and identifying genes that do not have big invasive problems. Furthermore, to work along with the existing ministries, a new administration is to be established in Turkana which will deal with *Prosopis juliflora* related issues and 100 Million USD is already budgeted for four years.

Q11*: One of the Prosopis juliflora controlling mechanisms is biological method. Is there anything threatening us not to use biological control?*

A11: Australia and South Africa are using biological control. They have imported natural enemy from the country which is origin of *Prosopis juliflora* but, these imported plants should not have negative effects. We are working on Parthenium and have found out that, it has no negative effect on biodiversity. From July 13-15, 2014 we have an international workshop on Parthenium and we are convinced that we are on the right track. But in case of *Prosopis juliflora*, we are looking for an international support.

Q12*: How can we be sure that, biological control species cannot have an impact on the biodiversity?*

A12: In Kenya, it never worked but, South Africa is doing well in this regard. We do not know how successful the biological measures are but there are lessons to be shared.

Presentation 11
The presentation was made by Herrie Hamedu which is entitled "Local perceptions on *Prosopis juliflora* invasion and socio-economic impacts of the tree in Southern Afar".

The presentation discusses on what the local perception on *Prosopis juliflora* invasion look like. During the time of its introduction, *Prosopis juliflora* was considered as good means of protection from intense solar radiation. Later on, as it began to claim more grazing and croplands, the local community started to be worried. And when the extent of invasion increased and people suffer from shortage of grazing and cropland, they have become frustrated and started to look for solutions. Very few individuals believe that, *Prosopis juliflora* is economically important. When the majority of the community members observe that, most of the control measures fail, they believe that the introduction and spread of the tree is a 'curse' from Allah and thus the solution too comes from Allah.

It also proposes the perception of the local community on the control measures.

- Clearance of the tree by cutting or burning
- Control through utilization mainly charcoal making, fence and house construction
- Engagement in other livelihood systems (crop production)
- Continuous use of land for irrigation based fodder and cereal crop production as the community is ready to supply labor and land resource
- Need supports like supply of agricultural inputs (tools and improved seeds, machineries and technology)

Finally, it describes the impacts of local mitigation measures

- Clearance by cutting and burning is only a temporary solution-it is usually followed by reemergence of the tree
- Charcoal making too facilitates the spread of the tree
- Charcoal making also has some socio-cultural impacts
- Dilution of cultural and social norms by outsiders

Presentation 12
The presentation was made by Mohammed Detona which is entitled "Socio-Economic impacts of *Prosopis juliflora* related charcoal trade in Gewane Woreda".

The study reveals that, charcoal business was started in 2004 by Cooperatives which were established by Farm Africa- an international NGO. The objectives of the charcoal business were to clear *Prosopis juliflora* invaded land, to use the cleared land for crop production and to change the *Prosopis juliflora* in to beneficial through production of charcoal. But, currently, the business is illegally expanding in which it is owned by young Afar men and highlanders. The charcoal makers are migrants from SNNP, Oromia and Amhara. Young afar men are involved as guards for charcoal makers and receive small payment from the charcoal owners. There are also Afar which benefit from this business by collecting illegal tax at the bridges and road side.

The negative impacts of this business include: Women are raped and killed by charcoal makers, increasing incidences of killing people by lions; high corruption due to illegality of the charcoal trade, Woreda administration loses tax income through illegality (estimated to be 60,000-80,000 Birr per day), cutting of indigenous trees such as acacia, and weakening of indigenous natural resources management institutions. These impacts were confounded by the fact that, the existing rules and regulations are not implemented, lack of political commitment and an indirect involvement of some of the governmental officials in the business.

Presentation 13
The presentation was made by Wondimagegne Chekol which is entitled "*Prosopis juliflora*, Parthenium & beyond: Elements for an integrated strategy of Invasive Alien Species (IAS) control in the Afar Region".

The study reveals that, there are about 35 IAS in Ethiopia and of which Parthenium hysterophorus and Acacia nubica are the two most important invasive species in Afar next to *Prosopis juliflora*.

Presentation 14
The presentation was made by Hannes Etter which is entitled "Restoring Namibia's bush encroached savanna".

This presentation reveals how to design incentives based on economic added value- example are livestock production, Rehabilitation & water provision and energy production (Wood combustion plant). It also discusses the value chain analysis of the restoration process. It also discusses about the involvement of private sector on sustainable land rehabilitation and to what degree government subsidies should go.

Presentation 15
The presentation was made by Sharrafadine Saleh which is entitled "Mesquite tree plantation in Yemen: Impacts and management practices".

This presentation provides the overview of *Prosopis juliflora* in Yemen and discusses how it was introduced in 1976 by FAO to rehabilitate desert areas. *Prosopis juliflora* currently covers, 240,000 ha of land in Arid and semi-arid areas of Yemen. Its main advantage is it has covered many arid and semi-arid lands and its main disadvantage is encroached areas of spate irrigation, it has blocked the main canal route and it is affecting wadis by changing the river morphology.

Questions rose for the five presentations (Presentation 11 to 15)

Q13: *How is the local community involved in the charcoal trading system and how is the benefit shared among the trade chain actors? In addition, the charcoal business looks like legal, what makes it look legal? Has the government indorsed the proclamation on charcoal business?*

A13: The charcoal traders pay money at every check point (mostly bridges) and charcoal farming plots. They also pay for cutting indigenous trees and changing them in to *Prosopis juliflora* plantation. In this way they manage to reach Addis Ababa and other nearby big cities. The main benefiting parties are the highlanders who are involved in the business along with the clan leaders. Some of the community members are also involved as a guard which benefit as small as 200 Birr/month. But, there are members of the community (the majority) who are regarded as losers. There are rules and regulations about the charcoal business but they have not yet been exercised.

Q14*: Is Prosopis juliflora used for feeding domestic animals like cattle, goat or camel and do you face animal diseases due to feeding also how is it managed?*

A14: The issue with the *Prosopis juliflora* feeding is, the sugar content of its pods is too high. As a result it has to be mixed with grinded maize or millet. Its proportion has to be 10% grinded *Prosopis juliflora* pods with 90% grinded maize or millet, and the *Prosopis juliflora* ratio should not exceed 10%. Furthermore, *Prosopis juliflora* thorns damage animals hence, the feed should be without the thorns and the animals should be feed away from the *Prosopis juliflora* plant locations.

Q15*: From the beginning up to now, what are the efforts made by the extension agents in raising the awareness of the community?*

A15: Local NGO's like CARE and FARM AFRICA and the regional government of Afar are working on raising the awareness of the community. The best thing to control/eradicate *Prosopis juliflora* is to work with the traditionally existing institutions as they can easily raise the awareness of the community.

Group Discussions

- Acknowledging clans and working with them will enable to achieve what is required.
- As total eradication of *Prosopis juliflora* is a difficult task, our approach should focus on contained management with an objective to fully utilize the destroyed *Prosopis juliflora* and restricting animals and men not to inter.
- We should work on selected areas first.
- The management aspects could be biological, chemical, mechanical or all integrated in one.
- There are four steps of management strategy
    I. Prevention – for free areas
    II. Containing – for established areas
    III. Clearing – requires technologies and investment
    IV. Restoration
- The political leadership should be involved and act on allocating budget.
- Scientific advisory board consisting of multidisciplinary professionals should be establishes to advice the political leadership, facilitating proposals and funding opportunities.
- Mekelle University, Semera University, BoPAD and research institutes have shown their commitments and this is a good foundation for the required activities. Hence, they should be involved in undertaking researches and development activities.
- Working on raising awareness from regional → country →national →local levels.
- IGAD should also work on coordinating the regional issues
- Every responsible institute including local and international NGOs should be involved.
- Training needs and local capacity buildings on charcoal making and other productive uses of *Prosopis juliflora* that would address the traditional knowledge is very important.
- Coordinating all efforts, establishing institutional mandates and defining who is responsible for what among the involved stakeholders needs to be addressed.
- Strengthening partnerships among stakeholders and building networks for exchange of best practices, sharing experiences and knowledge and taking lessons within the east Africa communities is imperative.
- The regional government of Afar should prioritize *Prosopis juliflora* control and management activities.
- Give recognition to charcoal traders who use only *Prosopis juliflora* for charcoal.
- Avoid focus on agriculture as only option for a reclaimed land.
- Collect more information on spreading mechanisms.
- Joint clearing and land utilization.

17.3 Recommendations and the way forward

- Irrespective of whether 'complete eradication' or 'controlled management' is chosen as the preferred approach, the underlining principle should that any intervention should generate benefits for the key stakeholders
- A leading and responsible institution is necessary to coordinate complete eradication or controlled management initiatives undertaken by different stakeholders

- Any initiative to succeed and the lead institution to be effective, all relevant stakeholders from national to district level as well as the local traditional institutions should work collaboratively.
- Present research findings in a language that can be understood by policy makers. The findings should clearly outline the risks, economic benefits and sustainability of alternative *Prosopis juliflora* control and management interventions.
- Integrating *Prosopis juliflora* management in to the regional or federal land use planning policy
- Integrate *Prosopis juliflora* control and management into existing national to district level natural resources management and development programs. This could, among others, ensure adequate budgeting
- National and local television and radio programs should play an important role in raising awareness levels about the extent of the problems caused by *Prosopis juliflora*. This could be done by broadcasting documentary videos, workshop sessions, and interviews with key stakeholders.
- *Prosopis juliflora* is a trans-boundary issue, regional bodies such as IGAD have vital role to play in coordinating efforts among different countries. IGAD should also mainstream *Prosopis juliflora* control and management in to its plan.

Finally, the conference was closed by forwarding closing remarks via the Academic vice president of Mekelle University, Dr. Abdulkadir Kedir, and Hon Christopher Eporon Ekuwom, Turkana Ministry for Pastoral Economy and Fisheries, Kenya.

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UNESCO-IHE
Institute for Water Education

Regional Conference on Managing *Prosopis Juliflora* for better (agro-)pastoral Livelihoods in the Horn of Africa

01 – 02 May, 2014
Desalegn Hotel, Addis Ababa, Ethiopia

Programme

Day 1 - Research

Time	Event	Speaker
8:30 – 9:00	Registration	
9:00 – 9:10	Welcoming address	Dr. Abdelkader Kedir (Mekelle University)
9:10 – 9:30	Introduction of the conference	Nadine Guenther (GIZ), Abraham Mehari Heile (UNESCO-IHE), Atinkut Mezgebu (Mekelle University)
9:30 – 9:50	Official opening remarks	State Minister MoA, Fritz Jung (German Embassy)
9:50 - 10:10	Introduction of Participants	
10:10 – 10:30	A history of Prosopis spread in Baadu, Ethiopia from a socio-ecological perspective	Simone Rettberg (University of Bonn)
10:30 – 10:50	The ecological impacts of Prosopis spp. on soils, plant species and C-stocks in infested regions of Afar	Abeje Eshete Wassie (Ethiopian Institute of Agricultural Research)

Time	Event	Speaker
10:50 – 11:20	Health break	
11:20 – 11:40	The Costs and Benefits of Inaction: An economic assessment of the impact of *Prosopis* invasion and participative management approaches in the Afar region, Ethiopia	John Ilukor (University of Hohenheim)
11:40 - 12:00	Households' demand for mitigation of Prosopis Juliflora invasion in the Afar Region of Ethiopia: a Contingent Valuation	Mesfin Tilahun (University of Mekelle)
12:00 - 13:00	Discussion	
13:00 – 14:00	Lunch	
14:00 – 14:20	Household perception about Prosopis juliflora and its effect on pastoral livelihood diversification strategy: the case of Gewane District in Afar Regional State, Ethiopia	Mohammed Jemaneh Seid (Afar Pastoral and Agro-pastoral Research Institute, Ethiopia)
14:20 – 14:40	Gender aspects of Prosopis Juliflora: perceptions, impacts, and coping strategies	Helena Inkermann (University of Bonn)
14:40 – 15:00	Mesquite trees infestation of the Gash spate irrigation system in Kassala state, Sudan: Impacts and remedial measures	Hamisi Said Nzumira (UNESCO-IHE)
15:00 – 15:30	Health break	
15:30 – 16:30	Discussion	
16:30- 16:45	Summarized results of the Rangelands Management Platform conference held in Addis Ababa on 16 April 2014: Prosopis juliflora in Ethiopia's Rangelands	Fiona Flintan (ILC, ILRI)
16:45 – 17:00	Wrap-up of the day	Nadine Guenther (GIZ)
19:00	Dinner at cultural restaurant	

Day 2 - Experiences

Time	Event		Speaker
9:00 – 9:10	Welcoming and opening remark		Minister Turkana, Kenya Abraham Mehari Haile (UNESCO-IHE)
9:10 – 9:30	Controlling and/or Using Prosopis Juliflora in Spate Irrigation Systems		Frank Van Steenbergen (MetaMeta)
	Parallel session I	*Parallel session II*	
9:30 – 9:50	a) Experiences of EIAR in Prosopis management and control in Afar	b) Management of invasive Prosopis trees: global examples that informed approaches for Kenya	a) Wondmagegne Chekol (Saint Mary's University) b) Simon Choge (KEFRI)
9:50 – 10:30	Presentation by session rapporteurs and discussion		a) Petra Jacobi (GIZ) b) Ali Alex Gulleid (MoALF, Marsabit, Kenya)
10:30 – 11:00	Health break		
	Parallel session I	*Parallel session II*	
11:00 – 11:20	a) Restoring Namibia's bush encroached savanna: An economic showcase for ecosystem service rehabilitation	b) Local perceptions of the spread of Prosopis in Baadu: socio-economic impact and management visions	a) Hannes Etter (GIZ) b) Herrie Hamedu (FAO)
11:20 – 11:40	a) Mesquite tree plantation in Yemen: Impacts and management practices	b) The impact of prosopis related charcoal trade in Gewane Woreda, Afar Region	a) Dr. Sharafaddin A. Saleh (Spate Irrigation Network) b) Mohammed Detona (University of Addis Abeba)
11:40 - 12:00	Prosopis, Parthenium and beyond: challenges for an integrated strategy of IAS control in the Afar region		Irmfried Neumann (Consultant), Wondmagegne Chekol (Saint Mary's University) N.N.
12:00 – 13:00	Presentation by session rapporteurs and discussion		Irmfried Neumann (Consultant) Tino Hess (GIZ)
13:00 – 14:00	Lunch		
14:00 – 14:30	Video documentation on "Prosopis juliflora in Afar, Ethiopia: Status, impacts and remedial measures"		Eyasu Yazew (University of Mekelle)
14:30 – 14:45	Reflection on the video		Participants

Time	Event	Speaker
14:45 – 15:00	Setting discussion agenda for the way forward and group formation	Participants
15:00 – 15:30	Health break	
15:30 – 16:30	Group discussions	Group members
16:30 – 17:00	Group presentations	Group representatives
17:00 – 17:10	Summary of outcomes on the way forward	Eyasu Y./Nadine G.
17:10 – 17:15	Official closing	Dr. Abdelkader Kedir (Mekelle University)

Published by
Deutsche Gesellschaft
für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn,
Germany

Sector Project Rural Development
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn
Germany
Tel. +49 (0) 6196 79 - 0
Fax +49 (0) 6196 79 - 1115

rural.development@giz.de
www.giz.de

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Cover © Simone Rettberg

As at
May 2015

GIZ is responsible for the content of this publication.

On behalf of
Federal Ministry for Economic Cooperation and Development (BMZ),
Special Unit “One World, No Hunger”

Addresses of the BMZ offices

BMZ Bonn
Dahlmannstraße 4
53113 Bonn
Germany
Tel. +49 (0) 228 99 535 - 0
Fax +49 (0) 228 99 535 - 3500

BMZ Berlin
Stresemannstraße 94
10963 Berlin
Germany
Tel. +49 (0) 30 18 535 - 0
Fax +49 (0) 30 18 535 - 2501

poststelle@bmz.bund.de
www.bmz.de