Journal of Sustainable Development in Africa (Volume 26, No.1, 2024)
ISSN: 1520-5509
Pennsylvania Western University, Clarion, Pennsylvania

IMPACTS OF *PROSOPIS JULIFLORA (*SWARTZ DC.) INVASION ON FOOD SECURITY OF PASTORAL AND AGRO-PASTORAL COMMUNITIES IN MIDDLE AWASH, AFAR REGION OF ETHIOPIA

Ameha Tadesse[1], Degefa Tolossa[1], Solomon Tsehaye[1], Desalegn Yayeh[1] , [1]Center for Food Security and Development Studies, Addis Ababa University, Addis Ababa, P.O. Box 150129, Ethiopia;

ABSTRACT

This study examined the impact of *Prosopis juliflora* invasion on the food security and welfare of pastoralist communities by taking two Woredas (as treatment and control group) in Afar regional state, Ethiopia. The study used a total of 438 randomly selected samples of households (224 from Amibara - invaded area) and (214 households from Awash Fentale - non-invaded area). Descriptive statistics and econometric methods using alternative Propensity Score Matching (PSM) model specifications were employed to estimate the effect of *Prosopis juliflora* invasion on the food security in the study area. Econometric results indicated that households in *Prosopis juliflora* invaded areas were more likely to have lower number of livestock assets, less access to veterinary and government support services. They are also less likely to have better access to marketplaces to sell their livestock/agricultural produces compared to those in non-invaded areas However, they are more likely to be older and married households compared to those in non-invaded areas. Results from Average Treatment Effect estimation indicated that households in invaded areas (on average) have 1,167 Birr lower annual consumption expenditure compared to those in non-invaded areas. Hence, it is important for the regional and local administration to understand the adverse impact of *P.juliflora* expansion on sustainable development of the rangelands of the area and related livestock productivity and consider the policy implications of the findings and follow some of the recommendations derived from this study.

Keywords: Food Security, Prosopis juliflora, Invasion, Amibara, Awash Fentale

INTRODUCTION

The impact of *Prosopis juliflora* invasion/ecological expansion on the sustainable development of pastoralists' livelihoods in the Afar Region of Ethiopia can be significant and multifaceted. *Prosopis juliflora* is recognized as one of the most invasive alien plant species in the world and has been introduced in the past 200 years and is now widespread in various parts of the world (Holmgren 2003, Pasiecznik et al. 2001). Although the exact date of introduction of *Prosopis juliflora* into Ethiopia and particularly in the Afar Region is not well known and documented, most of the local people and different institutions of the area agreed that the species was introduced to the region during the early 1970s (Haregeweyn et al. 2013, Tessema 2012, Shiferaw et al. 2004, Sintayehu, Dalle, and Bobasa 2020, Ayanu et al. 2015). Since then it has been expanding and increasingly invaded large areas of communal rangelands (Birhane et al. 2017). In 2006, a total of 490,000 ha (5.2% of the region) of land in Afar was invaded by *Prosopis juliflora* and then after, has covered an area of more than a 1.17 million ha (12.33% of the region) in Afar (Shiferaw et al. 2019) and more than 12,000 hectares in Dire Dawa Administration (Jema and Abdu 2013) and it has also invaded many rangelands in a different part of Ethiopia (Sintayehu, Dalle, and Bobasa 2020, Wakie et al. 2014, Hundessa and Fufa 2016, Lemma and Mohammed 2016).

Studies indicated that *Prosopis* has pros and cons, and many countries utilize *Prosopis juliflora* for different purposes such as its pods having nutritive value as food for humans and feeds for animals, its wood for different wooden products and its positive effect on soil amelioration in arid and semi-arid regions (Harden and Zolfaghari 1988, Alves et al. 1990). It is also used for firewood and charcoal and has high timber quality, its wood is used for making parquet/ wooden floors, furniture and turnery items, fence post (Feleker and Bandurski 1979, Roy 2011, Adodo and Iwu 2020, Pasiecznik et al. 2001).

On the other hand, *Prosopis juliflora* has been creating problems to the ecosystems, biodiversity, health, socio-economics, and several aspects of human welfare (Pasiecznik et al. 2001). The most ecological impacts of *Prosopis juliflora* is due to its dense canopy cover and related influences on light transmission to the ground which in turn results in changes and suppression of the undergrowth species or vegetation (Zeila 2011, Hussain et al. 2021) as a result it affects the sustainable productivity of the livestock in the area due to lack of enough pasture in the Prosopis invaded rangelands. In highly *Prosopis juliflora* invaded areas, it is found that the growth of native grass, herbaceous plants and tree diversity is suppressed (Ilukor et al. 2016b, Kahi 2004). In line with this some other study also indicated that if the optimal invasion dose (intensity) of *Prosopis juliflora* is above 22.23%, it will create a negative impact on the biodiversity as well as the income of the households (Bekele et al. 2018). As local elders in Afar indicated, *Prosopis juliflora* has been killing a larger number of cattle than those killed by drought, and which indicates how much *Prosopis juliflora* potentially leading and significantly affecting the pastoralism livelihood system and sustainable development of rangelands in the area. The Afar region boasts a cattle population of roughly 1.6 million, with approximately 131,000 of these cattle residing in the Amibara District. The primary purposes for keeping livestock in this region are for milk and meat production, as well as generating income (Ilukor et al. 2016a).

On the other hand, a study on climatic suitability model analysis for Prosopis indicated that more than 95% of the country was non-suitable for *Prosopis juliflora* growth are now becoming highly suitable (Sintayehu, Dalle, and Bobasa 2020). In 2050, both moderately and highly suitable area for *Prosopis juliflora* is expected to be increased (Sintayehu, Dalle, and Bobasa 2020, Bogale and Tolossa 2021). This revealed that the climatic suitability for *Prosopis juliflora* invasion will increase and create a conducive environment for *Prosopis juliflora* expansion and threaten the livelihoods of the community (Dakhil et al. 2021). Key adverse consequences of climate variability in Ethiopia encompass food insecurity due to droughts and floods, disease outbreaks, and land degradation caused by heavy rainfall (Bogale and Tolossa 2021). Moreover, *Prosopis juliflora* quickly invades pasture lands and severely affects households' income from livestock production (Wakie, Laituri, and Evangelista 2016, Zeray et al. 2017). It is also indirectly increasing household health expenditure (Ayanu et al. 2015, Haregeweyn et al. 2013, Bekele et al. 2018) due to creating severe injuries to the hooves of animals and have equally affecting human health.

Some community-level discussions revealed that there is a conflict of interest between pastoralists and urban dwellers in Afar on *Prosopis juliflora,* in a way that all pastoralists viewed *Prosopis juliflora* as no advantage whereas those community groups engaged in firewood and charcoal production considered as useful tree and means of income through sale of firewood and charcoal. A study indicated that the sales from charcoal and fire woods constitutes around 26% of the average annual income of the households (Jema and Abdu 2013). An increase in *Prosopis juliflora* invasion resulted in the loss of indigenous grasses and other plant species which in turn contributed to the substantial reduction of the number and productivity of livestock in Afar (Yosef et al. 2013, Herrie 2014). Livestock populations especially cattle and camel in the Amibara declined at a rate of 36% and 20%, respectively, between 1997 and 2011 (Ilukor et al. 2016b, Haregeweyn et al. 2013). Many of previously rich pastoralists with having large number of livestock in Afar are started living under food insecurity (Rettberg 2010) due to loss of their livestock. The rising global demand for livestock products is driven by the continuous improvement of living standards over time. Furthermore, climate change poses a significant threat to the sustainability of livestock production, affecting the quality of feed crops and forage, the availability of water, animal and milk production, livestock health, animal reproduction, and biodiversity (Rojas-Downing et al., 2017). Animal-based products play a vital role in the nutrition, food security, livelihoods, and resilience of hundreds of millions of people worldwide.

The number of livestock is declining time to time as households are selling off animals to buy food items, and about 64% of the rural Afar households are consuming less than three food groups out of seven (Ilukor et al. 2016b, Ethiopia and Headquarters 2014). In Ethiopia, Afar region, has the households with the highest food expenditure and malnutrition as well as the lowest household food stock per capita (1 kg/person) (WFP 2009).

Many pastoralists are moving into sedentary life within the last 20 years and engaging into different alternative income-generating activities (Rettberg 2010, Rettberg and Müller-Mahn 2012, Ilukor et al. 2016a). There are limited livelihood diversification and sustainable development options or alternatives in Afar to cope with this food insecurity challenges. Some of the studies conducted so far in Afar related to *Prosopis juliflora* primarily focus on its expansion/coverage, ecological and environmental impact, and means of utilization as a useful resource; some of them have dealt with the biological characteristics that promote its invasive ability and its impact on ecological services. However, studies that examine the impact of *Prosopis juliflora* invasion on the pastoralists' and agro-pastoralists' food security are rare. Hence, this study examined the impact of *Prosopis juliflora* invasion on food security using alternative estimation strategies to check the robustness of the results from PSM estimation.

CONCEPTUAL AND ANALYTICAL FRAMEWORK

Basic concepts

The concept of food security gradually broadened during the 1980s a move from global and national-level issues into food security concerns at local, household, and individual levels. The 1996 World Food Summit adopted the following definition that is more complex: *"Food security at any level is defined as physical and economic access by all people at all times to enough, safe, and nutritious basic food to meet their dietary needs and food preferences for an active and healthy life"(FAO 1996)*. Then later the concept of social access was introduced in the definition, and it became, *"Food security is a situation that exists when all people, at all times, have physical, "social" and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (Cafiero et al. 2016, FAO 2009, Pinstrup-Andersen 2009). It involves the availability, accessibility, utilization, and stability of food. On the other hand, *Food insecurity* is a situation in which individuals do not have physical or economic access to the nourishment they need, and they have no access to resources to produce food or cash. A household is also considered food insecure if its dietary intake is less than 80% of the daily minimum recommended allowance (MRA) of caloric intake required for an individual to be active and healthy (Owino et al. 2014).

Analytical Framework

As per the thematic focus of empirical and theoretical reviews conducted; the impact of *Prosopis juliflora* invasion on food security/insecurity is interconnected with various factors and dimensions such as demographic, socio-economic characteristics and other institutional settings that are directly and indirectly affecting the communities, livelihood and local climate and land use and land cover changes. The study tried to identify how some of the socio-economic factors related to the changing of food security/insecurity situation of the communities of the study areas. The following conceptual framework is developed to show how some of the key issues under each factor (demographic, socioeconomic, and institutional) linked with and contributed to show the impact of *the Prosopis* invasion on the welfare and food security/insecurity of the communities in the areas.

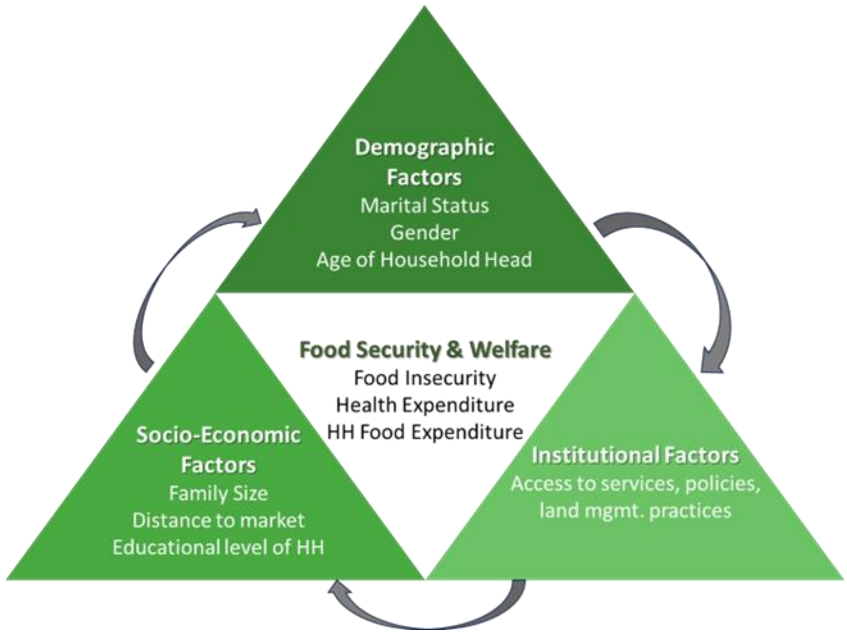

Figure 1. Conceptual Framework-impacts of *Prosopis juliflora* invasion on Food Security

Livestock assets ensure food security for pastoralists in the Afar Regions. The consumption of milk, meat, and other livestock products provides essential nutrients and sustenance for the community. During periods of drought or crop failure, when agricultural production is limited, livestock products serve as a reliable source of food. For instance, the Afar people heavily rely on camel milk, which is rich in nutrients and can be consumed even in times of water scarcity. Livestock assets contribute to the resilience of pastoralists, enabling them to withstand food shortages and maintain their livelihoods.

METHODOLOGY

Study sites

The study is carried out in Afar Regional State (ANRS), Awash Fentale, and Amibara Woredas (40°08'- 40°12'E and 09°16'- 09°21' N) and which is located 160 and 250 km from Addis Ababa respectively. The altitude of these study sites is between 740 and 820m above sea level(CSA 2021).The Afar National Regional State is part of the Great Rift Valley of East Africa.

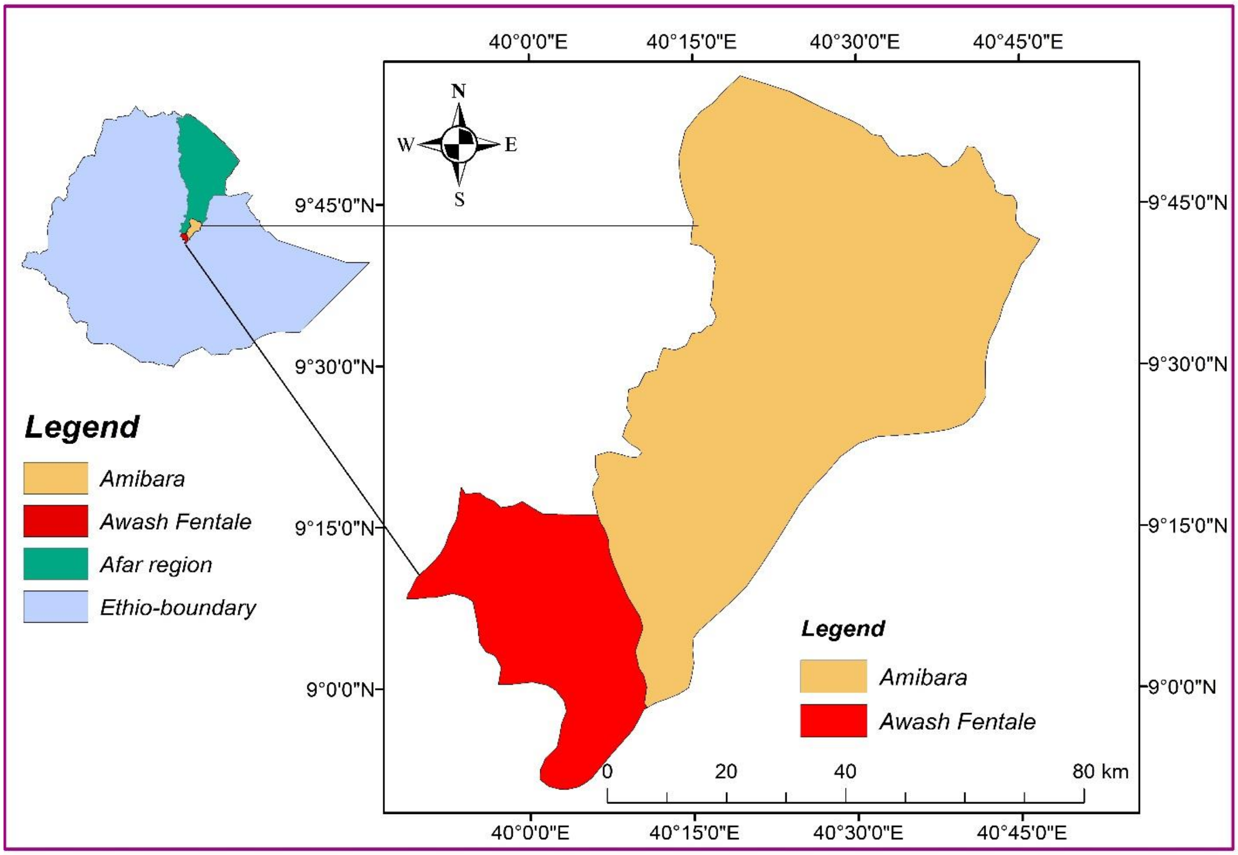

Figure 1: Map of study sites, Afar

The region covers 6.67 million ha which is about 10% of the total areas of Ethiopia and about 29% of pastoral lowlands (Shiferaw et al. 2019). It is arid and semi-arid with a mean annual temperature of 31 °C having erratic rainfall with annual precipitation between 200 and 600 mm. The region has about 1.99 million population (CSA 2021). The livelihood system of the region is mainly dependent on pastoralism (more than 90%) and agro-pastoralism (less than 10%) engaged in small-scale irrigation activities around the rivers. Most of the river in the areas are invaded by *Prosopis juliflora* (Ayanu et al. 2015, Ilukor et al. 2016b).

Shrublands, riverine forests, grasslands, wetlands, Settlements, and bare land are some of the key land use types in the areas. Encroachment of prosopis trees on grazing land is forcing pastoralists to move their herds to other areas in search of suitable grazing resources. This can disrupt traditional grazing patterns and lead to conflicts with other communities over limited resources. Forced migration can also result in the loss of social networks and cultural ties, further impacting pastoralists' livelihoods.

Figure 2: Cattle in *P. juliflora* invaded rangelands of Afar, Ethiopia

STUDY AREAS POPULATION AND ECONOMIC ACTIVITIES

The total population (urban and rural) of Amibara and Awash Fentale Woredas are 110,427 and 55,708, respectively, of which, the total rural population of Amibara and Awash Woreda are 86,133 (14,355 HHs) and 43,452 (7,242 households) respectively, whereas the average household size is seven (CSA 2021). The sale of livestock and livestock products, such as milk, meat, and hides, provides them with cash to meet their basic needs and invest in other income-generating activities. For example, the sale of goats or camels can help pastoralists purchase essential items like food, clothing, and medicine. Livestock assets also act as a form of savings, allowing pastoralists to accumulate wealth and cope with economic shocks, such as droughts or market fluctuations.

Sampling methods

The study used multi-stage sampling procedure to select Woredas and kebeles. First, when it comes to the selection of study region and woreda, Afar region- Amibara and Awash Fentale Woredas are chosen purposively as Amibara is the first most *Prosopis juliflora* invaded Woredas in Ethiopia and Awash Fentale is relatively free from *Prosopis juliflora* invasion. In the second stage, among all rural Kebeles in the two Woredas, *Prosopis juliflora* invaded (*Bedul Ali, Halaydege, Serkamo* and *Worer*) and non- invaded (*Doho, Dudub, Kebena* and *Sabure*) *Kebeles* were selected purposively in Amibara and Awash Fentale Woredas, respectively. Thirdly, a sample number of pastoralist and agro-pastoral households were randomly selected from the list of households obtained from each invaded and non-invaded *Kebeles* administration offices.

The sample households were selected for interview based on probability proportionate to the relative size of households in selected sample kebeles. First, the list of all households was collected from the *kebele* manager/administrator, and the list was used as a sample frame. In the circumstance when any randomly selected household head refused to participate in the interview are replaced by the next household. Data were collected using a pre-tested survey questionnaire. The survey was administered using experienced local language speaker data collectors using Kobo toolbox system in mobile/tablet for data collection. In addition, desk review was conducted and information from different sources was considered as input to develop a comprehensive survey questionnaire.

Sample size

The sample size for the study is determined by employing (Yamane 1973) formula to calculate the sample size from each Woredas of the rural population. The sample size calculation considered a 5% acceptable error (e=0.05); a 50% reasonable estimate for the key proportion to be studied (p =0.5); and a 95% confidence level. The formula is given as:

$$n = \frac{N}{\left(1 + N\ (e2)\right)} \qquad (1)$$

Where:

n = desired sample size

N= total number of population (i.e HHs)

e= the level of precision or the quality of being careful and accurate which is equal to 0.05.

Initially, the sample size for Amibara and Awash Fentale Woredas was estimated to 374 HHs and 336HHs, respectively. An additional 5% HHs were also considered to compensate for those respondents not willing to interview and which makes it a total of 746 HHs to be involved for household survey in both Woredas. However, considering the recurrent ethnic conflicts and security issues in *Zone 3* and the northern war effect in Afar and other related difficulties for field level data collection, the researcher in consultation with supervisors has decided and reduced the sample size, and data were collected from 438 households of the two Woredas (Figure 4).

Data collection tools and methods

The study was conducted following a preliminary assessment and review of relevant literature, local information, and observations. The researcher consulted with all relevant sectors and stakeholders during the study. Data collection tools and questionnaires were developed to effectively gather the required information from the field. As a result, the researcher collected both primary and secondary data from all available sources and household surveys. Field level data was collected during the lean season of the area, which was in January and February 2021. For primary data, both quantitative and qualitative surveys were conducted at household/individual level through well-developed survey questionnaires. Participatory community level discussions were employed to generate complementary and reliable data and information from different sectors at different levels. All food security data were collected from the sample *Woredas* and *kebeles*.

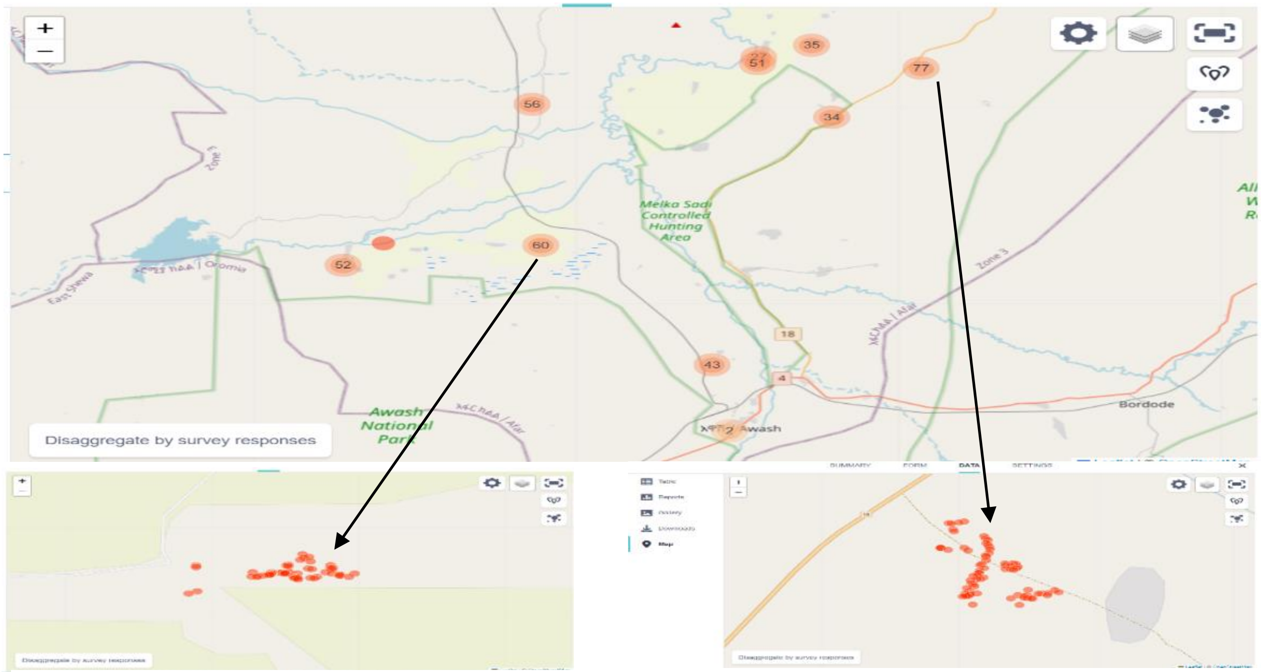

Figure 3: Sample sites and distribution of interviewed households by Woredas.

DATA ANALYSIS

The data were analyzed using descriptive statistics and econometric methods. Mean comparison tests using t- test and Chi square test were used to test whether there is a statistically significant difference across variables of interest between the two groups. The econometric method used propensity score matching techniques with alternative model specifications as a robustness check.

Propensity Score Matching technique

To estimate the effect of invasion on outcome variables (annual household expenditure, a good proxy for income/food security), propensity score matching technique (PSM) was used (Rosenbaum & Rubin, 1983). Propensity score matching (PSM) is a statistical technique used in treatment effect model estimations to reduce bias and mimic a randomized controlled trial (RCT) when analyzing observational data (Jema and Abdu 2013, Zeray et al. 2017). It aims to estimate the causal effect of a treatment or intervention by matching treated (invaded areas) and control units (non-invaded) based on their propensity scores. PSM process often requires the below steps: 1. Define the treatment and control groups: Identify the treatment group (those who received the treatment) and the control group (those who did not receive the treatment) from observational data. 2. Estimate the propensity scores: Propensity scores are the estimated probabilities of receiving the treatment based on observed covariates. A logistic and/or probit regression model may be used to estimate the propensity scores, with the treatment variable as the dependent variable and the covariates as independent variables. 3. Assess covariate balance: Check the balance of covariates between the treatment and control groups after estimating the propensity scores. Covariate balance ensures that the groups are comparable and reduces bias. Common methods to assess balance include standardized mean differences, t-tests, or chi-square tests. 4. Match treated and control units: Match treated units with control units based on their propensity scores. There are different matching methods available, such as nearest neighbor matching, exact matching, or kernel matching. The goal is to create pairs or groups of treated and control units with similar propensity scores. Overall, propensity score matching is a valuable tool in observational studies for reducing bias and improving the validity of causal inference regarding the effects of treatments or interventions. 5. Assess post-matching balance: After matching, reassess the balance of covariates between the treated and control groups. This step ensures that the matching process has successfully reduced bias and achieved covariate balance. Overall, assessing post-matching balance is essential for ensuring the validity, reliability, and interpretability of results obtained from propensity score matching. It allows researchers to evaluate the success of the matching process in creating comparable treated and control groups, thus improving the credibility of causal inferences drawn from observational studies. 6. Estimate treatment effect: Finally, estimate the treatment effect by comparing the outcomes of the treated and control groups. Common methods for estimating treatment effects in PSM include difference-in-differences, regression adjustment, or stratification.

It's important to note that PSM has assumptions and limitations. Assumptions include the confoundedness assumption (conditional independence of treatment assignment given covariates) and the common support assumption (overlap in propensity scores between treated and control units). Careful consideration and evaluation of these assumptions are crucial when using PSM for treatment effect estimation. Results in section 4.2 were presented having the above steps in consideration to improve the validity of observational studies such as in our case.

Relevant socioeconomic, demographic and related factors were hypothesized as factors influencing the probability of treatment assignment and the causal effects (average treatment effect). These includes income (livestock assets which can be measured in tropical livestock unit (TLU), TLU commonly takes 250 kg live weight as a standard of unit, and accordingly, the TLU conversion factor for camels, cattle, and small stocks is 1, 0.7, and 0.1, respectively (Jahnke and Jahnke 1982)) , age of household head, family size, education, marital status, access to veterinary services, and access to food aid (support services) (Table 4.2). Past studies and our own experience were used to select these covariates/explanatory variables that are expected to influence the probability of treatment assignment and the causal effect of *Prosopis juliflora* tree invasion on pastoralists livelihoods.

As a robustness check to our results, alterative propensity scores matching methods have been used using the matched datasets. Once the matching is done, the impact has been computed as follows.

$$T_{ATT}^{PSM} = E_{P(X)\,|\,\mathrm{D}=1}\{E\left[Y(1)\,\middle|\,\mathrm{D}=1, \mathrm{P(X)}\right] - E\left[Y(0)\,\middle|\,\mathrm{D}=0, \mathrm{P(X)}\right]\} \qquad (2)$$

Specifically, psmatch2 and kmatch commands with PSM option in Stata were used to estimate the effect of the explanatory variables on outcome variables (annual household expenditures- as proxy for food security/income) across treated and control groups (Table 4.2). The balance of covariates between the treatment and control groups were confirmed using density and cumulative density plots with distance kernel matching methods (kmatch command in Stata).

RESULTS AND DISCUSSION

Descriptive results

Socioeconomic characterization of the study area

The study used a total of 438 samples households from both Woredas, 224 from *Amibara* and 214 households from *Awash Fentale* Woredas where these are Prosopis invaded and non- invaded Woredas, respectively. Descriptive analysis on socioeconomic characteristics of the sample households indicate that the proportion of male headed households are 69.6% and 67.8% in invaded and non-invaded areas, respectively. While the average family size is 6.5 and 6.3 persons per household, the average age of household head in Prosopis-invaded and non-invaded kebeles was 38 and 37 years, respectively (Table 4.1, for tests of significant difference between areas).

In addition, by distance from the market, invaded and non-invaded households were 3.23 and 7.69 km away from the market, respectively. As indicated, the non-invaded area is relatively far from the market center which is in line with the fact that areas nearby to market centers have a high likelihood to be invaded as livestock are the main Prosopis disseminating agents. This is line with Nigussie *et al.,* (2018) who also noted that the average distance of non-invaded households from nearby city and main road is significantly far away than invaded areas.

Table 4.1: Socio-economic characteristics of households by treatment groups

Variables	Amibara (Invaded area)	Awash Fentale (non invaded area)
Family size in numbers	6.473	6.262***
	(0.13)	(0.17)
Age of household head in years	38.071	37.107***
	(0.62)	(0.78)
Distance from Market in km	3.230	7.689***
	(0.24)	(0.82)
Gender (1=Male)	0.696	0.678***
	(0.03)	(0.03)
Marital Status (1=married)	0.996	0.935***
	(0.00)	(0.02)
Assistance (1=Yes)	0.598	0.794***
	(0.03)	(0.03)
Vet-Access (1=Yes)	0.625	0.706***
	(0.03)	(0.03)
TLU (Tropical livestock unit)	21.343	23.705***
	(0.87)	(0.97)
Annual expenditure (ETB)	5247.661	6358.706***
	(123.39)	(227.00)
Income in ETB	2513.170	2687.477***
	(88.98)	(142.94)
N	224	214

Note: For mean comparison, t- test was used for continuous variables while Pearson chi2 for dummy/categorical variables. Standard errors are in parentheses. Tests of significance stars are shown on Awash Fentale column values instead of having a separate p-value column.

Results also indicate that households in the non-invaded area have better access to veterinary services, as the average accessibility of veterinary service is 70.6% for non-invaded area - Awash Fentale, while it is 62.5% for invaded area – Amibara

(Table 4.1). The difference in access to veterinary service between the groups is statistically significant at 1%. Access to social services including vet service is much better in non-invaded areas mainly because of the difficulty for livestock and others movement in invaded areas where Prosopis become thick and impossible for livestock and veterinary service providers to move from place to place. The less invaded the area, the more likelihood to provide services for pastoral communities which contributes a lot to enhance productivity of livestock and crops and related increase of incomes from sales of livestock products.

Since almost all households in the area are pastoralists, the invasion of Prosopis has also other implications for households accessing social services, including veterinary services. For one thing, it reduces livestock health management capability of the pastoralists. The difficulty for livestock to move freely in Prosopis-invaded areas may limit their access to regular veterinary check-ups, vaccinations, and treatments. Consequently, livestock health management and disease control measures could be compromised, leading to a higher risk of health issues among the animal population. According to Mehari (2015), invaded household lost about 7 cattle and 6.5 small stocks, on average, due to health threats resulted from the pods of *Prosopis juliflora*.

In addition, it has its own impact on the livelihoods of households. Livestock rearing is often a vital source of income and sustenance for communities in rural areas. The restriction of livestock movement in Prosopis-invaded areas can negatively impact the livelihoods of these communities by limiting their ability to trade, sell, or move livestock to access better grazing areas or markets. The fact that the households in non-invaded area have significantly higher income expenditure from the Table above could support this argument.

Finally, it is also found that households in invaded areas have less livestock number than households in non-invaded area (Table 4.1). This could be due to the impact of the *Prosopis juliflora* invasion on pastureland that support livestock production in the area. This is consistent with Mehari's (2015) result that most of the households in the area claimed to have lost more than half of their grazing lands due to the invasion. Figure 5 below shows the differences in the distribution of livestock (in Tropical Livestock Unit) between the invaded and non-invaded area. The test results using two-sample Kolmogorov-Smirnov indicated that there are statistically significant differences in TLU distributions between the treatment groups (combined K-S values at 0.1580; p-value=0.008). Hence, households in invaded region have lower TLU distributions or values than in non-invaded region (Figure 5). In this regard, noting the intentional introduction of the *Prosopis juliflora* in the area, Seid *et al*., (2020) also argued that the plant has become very invasive, and it severely harmed livestock rearing which is the main livelihood strategy of households in the study area.

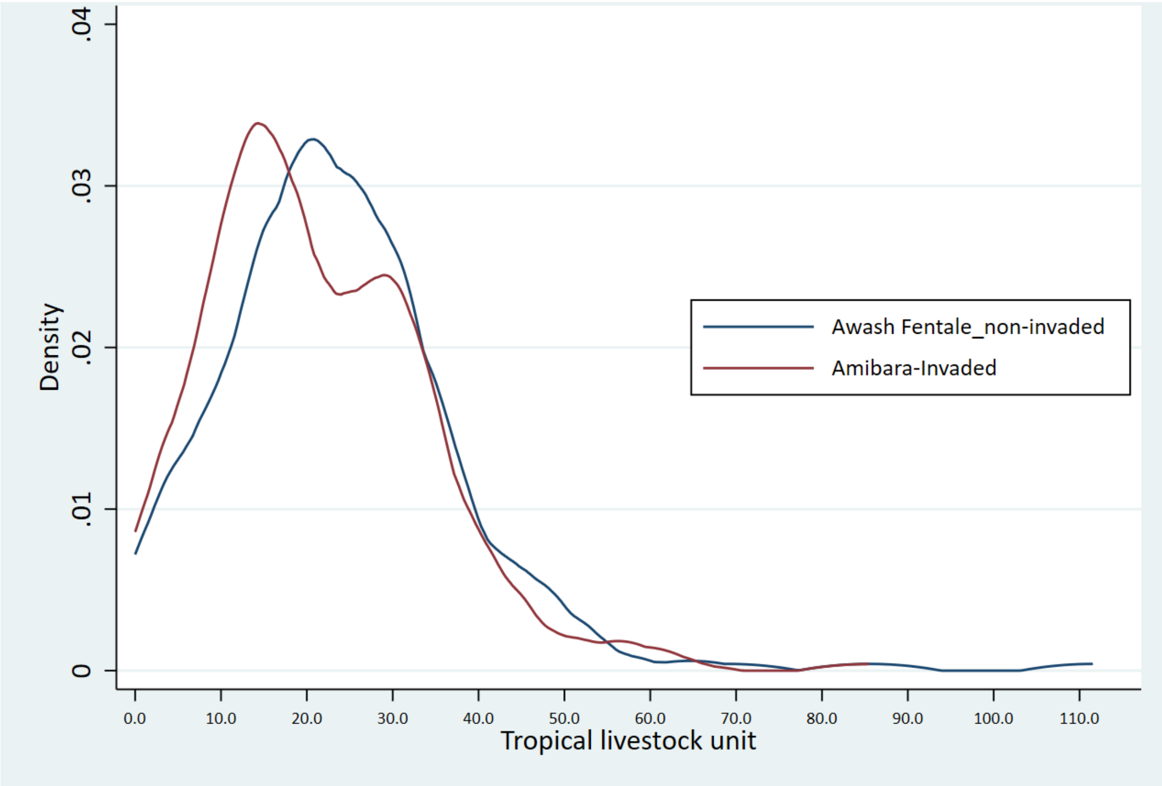

Figure 5: Differences in TLU distribution by Prosopis invasion, Afar Region of Ethiopia

Source: Own data visualization using Stata 17.1 version, 2023

Livestock serve as a source of income, allowing pastoralists to meet their basic needs and invest in other income-generating activities. They also act as a reliable source of food during periods of drought or crop failure. Moreover, livestock assets hold significant social and cultural value, symbolizing wealth, prestige, and fostering social cohesion. Therefore, the preservation and sustainable management of livestock assets are crucial for the well-being and resilience of pastoralists in the Afar Regions.

Econometric results

Probability of treatment assignment

The impact of the Prosopis invasive tree species on pastoralists' livelihoods in the Afar Region of Ethiopia can be significant and multifaceted. To identify the net impact of the invasion on the food security of households, the PSM matching technique was used in this study. Since results from PSM estimation are sensitive to the kind of matching methods applied and the underlying assumptions of the model such as no unobserved confounders between covariates and the outcome variable, this study presented estimation results using two alternative model specifications (Table 4.2). The balance of covariates between treatment and control was also checked before estimating the factors contributing to the treatment assignment and the causal effect of Prosopis invasion.

In order to check the quality of matching between the two groups, density balancing plot was used to compare the distribution of the covariates before and after matching, and it indicated that the matched groups have similar distribution after treatment as shown in the figure 6. This confirms the accuracy of the matching process that helps to eliminate selection bias in estimating the impact of treatment on outcome variable.

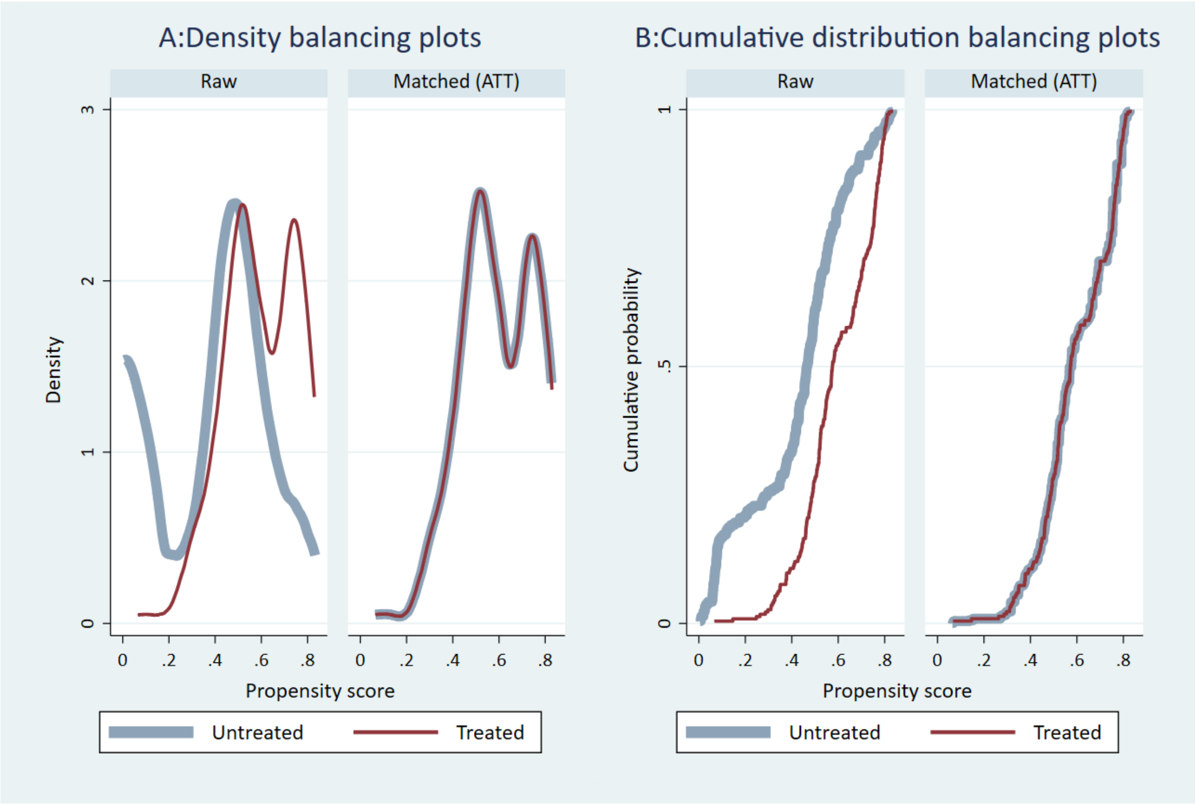

Figure 6: Accuracy of the matching process using kmatch graph command

Source: Own data visualization, 2023. See Jann (2017) for kmatch command in Stata 17.1.

Consistent results across models were obtained confirming the robustness of our estimation (Table 4.2). Since the overall model fit and standard errors were bootstrapped in kmatch (with probit model option), results from this model will be used and interpreted in this study.

As expected, households in treated areas were more likely to have lower number of livestock assets, less access to veterinary and government support services. They are also less likely to have better access to marketplaces to sell their livestock/agricultural produces compared to those in non-invaded areas. However, they are more likely to be older and married households (Table 4.2). These results support the descriptive results presented and discussed in Table 4.1 (previous section). It also confirms that Prosopis invasion is a treat to pastoralists livelihood strategy-livestock asset. This is because livestock is an asset that provides economic stability, ensures food security, and contributes to the social and cultural fabric, prestige, and fostering social cohesion of the pastoral community. Therefore, the preservation and sustainable management of livestock assets are crucial for the well-being and resilience of pastoralists in the Afar Regions.

Table 4.2: Propensity score matching estimation results

	psmatch2-logit b/se	Kmatch-probit b/se
Treatment equations-household characteristics		
Family size	0.003	0.004
	(0.05)	(0.03)
Male=1	0.067	0.048
	(0.23)	(0.14)
Married	2.419**	1.341**
	(1.08)	(0.53)
Age of household head in years	0.090*	0.055*
	(0.05)	(0.03)
Age of household head squared	-0.001	-0.001
	(0.00)	(0.00)
Education		
2nd cycle (5-8) grades	0.912	0.580
	(0.62)	(0.38)
Has no formal education	0.717	0.440
	(0.52)	(0.32)
High school (9-12) grades	1.116	0.698
	(0.89)	(0.54)
Technical / vocational certificate or diploma	0.663	0.420
	(1.55)	(0.90)
Market distance in km	-0.084****	-0.052****
	(0.02)	(0.01)
Assistance received 1=Yes	-1.067****	-0.641****
	(0.24)	(0.14)
Access to vet. Services 1=Yes	-0.483**	-0.279*
	(0.24)	(0.15)
Tropical livestock unit	-0.017**	-0.010**
	(0.01)	(0.00)
Constant	-3.174**	-1.831**
	(1.49)	(0.83)
Observations	438	438
LR chi2(13)	82.57	83.16
Prob >chi2	0.000	0.0000
Pseudo R2	0.136	0.137
Average Treatment effects estimation results	psmatch2	kmatch
ATT	-1112.6**	-1167.8***
SE-ATT	259.9	273.94
T_Stat	-4.28	-4.26
P_value	0.0000	0.0000

Note: * p<0.10, ** p<0.05, *** p<0.01. Outcome variable is household total expenditure in both models. In both models, regressions are on common supports. Standard errors are bootstrapped for kmatch model. A probit model with Mahalanobis-distance kernel matching (md) through bootstrapping of standard errors was specified for kmatch method.
Source: Own estimation, 2023

Average Treatment-Effect (ATT) estimation results

By matching individuals with similar propensity scores, the method aims to create comparable groups and reduce the bias caused by confounding[1] variables. The estimated treatment effect represents the average difference between the potential outcomes for the treated and control groups. As shown in Table 4.2, alternative PSM matching methods were applied using matched observations. Results from both models indicated that *Prosopis juliflora* invasion signficantly reduced pastoralists annual consumption expenditure although a relatively higher average treatment effect result was obtained from kmatch model compared to psmatch2 model (see Table 4.2, ATT row).

As expected, households in invaded areas (on average) have lower annual expenditure (e.g. 1,168 Birr) compared to those in non-invaded areas (see ATT row of Table 4.2 for kmatch model). Because expenditure is a good measure of food security compared to income measure, it can be inferred that those in invaded areas are more food insecure since they have less amount of money to cover their expenses. Statistically significant Average Treatment Effect (ATT) values from the `kmatch` command in Stata indicate that there is evidence to suggest that the treatment has had a significant impact on the outcome variable of interest. This finding supports previous studies' that examined the effect of this invasive plant on pastoralists livelihoods using mostly descriptive analysis. For example, 84% of pastoral households perceived *Prosopis juliflora* as a harmful bush (Mehari, 2015), and similarly about 90% of households have negative perception towards effects of *Prosopis juliflora* invasion on the rural community (Seid *et al*., (2020). Even more, according to Ilukor *et al*., (2016), most households favored whole eradication of the Prosopis.

CONCLUSION

This study examined the impact of *Prosopis juliflora* invasion on the food security and welfare of pastoralist communities in *Amibara and* Awash *Fentale* woredas of Afar region. A total of 438 randomly selected samples of households (224 from *Amibara* - invaded area) and (214 from *Awash Fentale* - non-invaded area) were interviewed using structured survey questionnaire with initial pre-testing. Both descriptive and econometric results were presented and discussed to examine the impact of this invasive species on pastoralists food security proxied by total annual expenditure. Unlike previous studies, this study uniquely examined the effect of this invasive tree on pastoralists key assets-livestock and additional covariates to disentangle the casual effects of *Prosopis juliflora* invasion on food security.

Using PSM technique combined with advanced methods for checking covariate matching and diagnostics, the average treatment effect of *Prosopis juliflora* invasion on pastoralists food security was estimated. The results from this matching method indicated that pastoralists in treated (invaded areas) were found to be food insecure (had lower annual income/expenditure) compared to the control groups (non-invaded areas). This may suggest *Prosopis juliflora* invasion, though intentionally introduced in the area, poses important food security and welfare concerns to pastoralists than the potential benefit it accrues from sale of charcoal and firewood for some members of the community.

---

[1] Variables that may affect both the treatment variable (indicator) and outcome variable simultaneously that may potentially result in spurious regression results.

Results from this study also indicated that pastoralists in invaded areas were more likely to have fewer number of livestock assets that holds significant (economic, social, and cultural values) to pastoralists compared to those in non-invaded areas. In addition, pastoralists in invaded areas were less likely to have access to veterinary and other support services compared to those in non-invaded areas. Limited access to veterinary services would mean pastoralists' ability to control livestock diseases could be compromised, leading to a higher risk of animal health and loss of livestock assets-a key livelihood strategy that contributes a lot for sustainable economic and social development for pastoral communities in the area. Given livestock rearing, a major means sustenance for the pastoral community, the restriction of livestock movement in Prosopis-invaded areas also tend to limit their ability to trade and access better grazing land, and hence negatively impact the livelihoods and the sustainability of livestock production by pastoral communities.

In addition, as part of sustainable development strategy, an understanding of the impacts of *P. juliflora* invasion enables pastoralists to build resilience against future threats to food security. By implementing measures to control invasive species and diversifying livelihood strategies, communities can become more resilient to environmental changes and disruptions. The study contributes to the development of sustainable livelihood strategies for pastoralists by identifying alternative income sources and land management practices that are compatible with ecosystem conservation and food security objectives.

RECOMMENDATIONS

The invasion of *Prosopis juliflora* trees in the Afar Region of Ethiopia poses significant challenges to pastoralists' livelihoods, including reduced grazing land, water scarcity, livestock health issues, and displacement. Addressing this invasive species and finding sustainable development solutions is crucial to ensure the resilience and well-being of pastoralist communities in the region. This study unveiled evidences that *Prosopis juliflora* invasion significantly impact the livelihood of the pastoralist community, especially in highly invaded areas of the region. Based on the study results, the following are important recommendations. First, develop methods to contain the spread of this invasive tree species. Such measures may include uprooting seedlings, cutting, and burning and use of modern technologies/machinery such as (e.g., pod and tree crushing machines). The use of modern tree crushing machines may create job opportunities and by products (feed resources).

Second, encourage pastoralists to diversify their livelihood strategies. Since the main livelihood strategy of the households in the area is livestock rearing, anything that affects this huge asset cannot be overlooked. As the plant takes over grazing land, sucks water from soil, and cause harm due to its poisonous thorns, among others, that significantly reduced the number of livestock in invaded area, livelihood diversification strategies may also be sought as complete eradication of the plant may not be possible. Thus, pastoralists in the area may be provided proper agricultural extension services to combine crop production activities along with their livestock rearing. Additional non-farm income generating activities and initiatives may also be looked at since pastoralists key asset (livestock) is under significant treat by *Prosopis juliflora* invasion.

Third, it is also vital to search for technological options. The invasion of the tree is already an issue on other part of the world including Asia (e.g., India), Latin America and Southern Africa in particular. Collaborative research works may be needed to pull varied experiences and resources together that geared towards coming up with some innovative solutions to deal with the plant.

Conflict of interest statement

The authors declare that they have no conflicts of interest related to this manuscript.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and heartfelt gratitude to my supervisors for their unwavering guidance, encouragement, and invaluable feedback, all of which contributed significantly to the success of this research. Additionally, I extend my thanks to the reviewers and editor of the journal for their constructive feedback and insightful comments, which greatly enhanced the quality of this paper. Furthermore, I am deeply grateful to the communities, elders, and officers of the study areas for their generous contributions, valuable insights, and the wealth of information they shared, which enriched the outcome of this study.

REFERENCES

Adodo, Anselm, and Maurice M Iwu. 2020. *Healing plants of Nigeria: Ethnomedicine and therapeutic applications*. Vol. 15: CRC Press.

Alves, JLH, MSA Melo, GD Alves, Habit MA, and Saavedra JC. 1990. "The current state of knowledge on Prosopis juliflora." *Fao, Rome, Italy* 187.

Ayanu, Yohannes, Anke Jentsch, Detlef Müller-Mahn, Simone Rettberg, Clemens Romankiewicz, and Thomas Koellner. 2015. "Ecosystem engineer unleashed: Prosopis juliflora threatening ecosystem services?" *Regional Environmental Change* 15 (1):155-167.

Bekele, Ketema, Jema Haji, Belaineh Legesse, Hailu Shiferaw, and Urs Schaffner. 2018. "Impacts of woody invasive alien plant species on rural livelihood: Generalized propensity score evidence from Prosopis spp. invasion in Afar Region in Ethiopia." *Pastoralism* 8 (1):1-17.

Birhane, Emiru, Anna C Treydte, Abeje Eshete, Negasi Solomon, and Mengsteab Hailemariam. 2017. "Can rangelands gain from bush encroachment? Carbon stocks of communal grazing lands invaded by Prosopis juliflora." *Journal of Arid Environments* 141:60-67.

Bogale, Girma Asefa, and Tasisa Temesgen Tolossa. 2021. "Climate change intensification impacts and challenges of invasive species and adaptation measures in Eastern Ethiopia." *Sustainable Environment* 7 (1):1875555.

Cafiero, C, M Nord, S Viviani, M Del Grossi, T Ballard, A Kepple, M Miller, and Ch Nwosu. 2016. "Methods for estimating comparable rates of food insecurity experienced by adults throughout the world." *Rome: FAO*.

CSA. 2021. Pupulation Projection The Federal Democratic Republic of Ethiopia, by Centeral Statistical Agency Report; Addis Ababa, Ethiopia

Dakhil, Mohammed A, Ali El-Keblawy, Mohamed A El-Sheikh, Marwa Waseem A Halmy, Taoufik Ksiksi, and Walaa A Hassan. 2021. "Global invasion risk assessment of Prosopis juliflora at biome level: does soil matter?" *Biology* 10 (3):203.

Ethiopia, WFP, and WFP Headquarters. 2014. "Comprehensive Food Security and Vulnerability Analysis (CFSVA)." by World Food Program, Addis Ababa, Ethiopia

FAO. 1996. Energy for sustainable development and food security in Africa. Food and Agriculture Organization Rome.

FAO. 2009. Declaration of the world summit on food security. FAO Rome, Italy.

Feleker, P, and RS Bandurski. 1979. "Use and potential of leguminous trees for minimal energy input." *Agriculture Economic Botany* 33:172-184.

Harden, ML, and Reza Zolfaghari. 1988. "Nutritive composition of green and ripe pods of honey mesquite (Prosopis glandulosa, Fabaceae)." *Economic Botany* 42 (4):522-532.

Haregeweyn, Nigussie, A Tsunekawa, M Tsubo, Damtew Meshesha, and Argaw Melkie. 2013. "Analysis of the invasion rate, impacts and control measures of Prosopis juliflora: a case study of Amibara District, Eastern Ethiopia." *Environmental monitoring and Assessment* 185 (9):7527-7542.

Herrie, H. 2014. "Socioeconomic and Ecological Impacts of Prosopis juliflora Invasion in Gewane and Buremudaytu Woredas of the Afar Region." *Managing Prosopis Juliflra for better (agro-) pastoral Livelihoods in the Horn of Africa. Addis Ababa, Ethiopia: GIZ*.

Holmgren, Milena. 2003. "The Prosopis juliflora-Prosopis pallida Complex: A Monograph-NM Pasiecznik, P. Felker, PJC Harris, LN Harsh, G. Cruz, JC Tewari, K. Cadoret, LJ Maldonado, HDRA Coventry, UK, 2001, 162 pp. ISBN: 0-905343301." *Forest Ecology and Management* 1 (174):605.

Hundessa, Niguse, and Amare Fufa. 2016. "Distribution and socio-economic impacts of Prosopis juliflora in East Shewa and West Arsi Zones, Ethiopia." *International Journal of African and Asian Studies* 24:31-41.

Hussain, M Iftikhar, Ross Shackleton, Ali El-Keblawy, Luís González, and M Trigo. 2021. "Impact of the invasive Prosopis juliflora on terrestrial ecosystems." *Sustainable Agriculture Reviews 52*:223-278.

Ilukor, John, Simone Rettberg, Anna Treydte, and Regina Birner. 2016a. "To eradicate or not to eradicate? Recommendations on Prosopis juliflora management in Afar, Ethiopia, from an interdisciplinary perspective." *Pastoralism* 6:1-8.

Ilukor, John, Simone Rettberg, Anna Treydte, and Regina Birner. 2016b. "To eradicate or not to eradicate? Recommendations on Prosopis juliflora management in Afar, Ethiopia, from an interdisciplinary perspective." *Pastoralism* 6 (1):1-8.

Jahnke, Hans E, and Hans Eberhard Jahnke. 1982. *Livestock production systems and livestock development in tropical Africa*. Vol. 35: Kieler Wissenschaftsverlag Vauk Kiel.

Jema, Haji, and Mohammed Abdu. 2013. "Economic impact of Prosopis juliflora on agropastoral households of Dire Dawa Administration, Ethiopia." *African Journal of Agricultural Research* 8 (9):768-779.

Kahi, Henry C. 2004. "The Effects of Prosopis julifora (DC) Hyne and Acacia tortilis (Forsk) Trees on Understorey Plant Species and Soil Properties on Njemps Flats, Baringo District, Kenya." by Department of Range Management, University of Nairobi, Kenya

Lemma, Berhanu, and Nejib Mohammed. 2016. "Distribution and socio-economic impacts of Prosopis juliflora in Gamo Gofa, segen area people and South Omo zones, southern Ethiopia." *Int J Agricul Sci Technol* 4 (1):19-27.

Owino, Abraham Y, Leonard K Atuhaire, Ronald Wesonga, Fabian Nabugoomu, and Elijah SK Muwanga-Zaake. 2014. "Determining factors that influence household food insecurity in Uganda: a case study of Tororo and Busia districts."

Pasiecznik, Nick M, Peter Felker, Phil JC Harris, LNa Harsh, Gastón Cruz, JC Tewari, Katel Cadoret, and Lorenzo J Maldonado. 2001. *The Prosopis juliflora-Prosopis pallida complex: a monograph*. Vol. 172: HDRA Coventry.

Pinstrup-Andersen, Per. 2009. "Food security: definition and measurement." *Food security* 1 (1):5-7.

Rettberg, S, and D Müller-Mahn. 2012. "Human-environment interactions: the invasion of Prosopis juliflora in the drylands of northeast Ethiopia." *Mol, L. and Sternberg. T.(Eds.): Changing Deserts-Integrating People and their Environments. Whitehorse Press, Cambridge*:297-316.

Rettberg, Simone. 2010. "Contested narratives of pastoral vulnerability and risk in Ethiopia's Afar region." *Pastoralism* 1 (2):248-273.

Roy, MM. 2011. "Prosopis juliflora: A valuable Species for Arid and Semi-arid Tropics." by Centeral Arid Zone Research Institute, India

Shiferaw, Hailu, Woldeamlak Bewket, Tena Alamirew, Gete Zeleke, Demel Teketay, Ketema Bekele, Urs Schaffner, and Sandra Eckert. 2019. "Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia." *Science of the total environment* 675:354-366.

Shiferaw, Hailu, Demel Teketay, Sileshi Nemomissa, and Fassil Assefa. 2004. "Some biological characteristics that foster the invasion of Prosopis juliflora (Sw.) DC. at Middle Awash Rift Valley Area, north-eastern Ethiopia." *Journal of arid environments* 58 (2):135-154.

Sintayehu, Dejene W, Gemedo Dalle, and Arbo F Bobasa. 2020. "Impacts of climate change on current and future invasion of Prosopis juliflora in Ethiopia: environmental and socio-economic implications." *Heliyon* 6 (8):e04596.

Tessema, Yibekal Abebe. 2012. "Ecological and economic dimensions of the paradoxical invasive species-Prosopis juliflora and policy challenges in Ethiopia." *Journal of economics and sustainable development* 3 (8).

Wakie, Tewodros T, Paul H Evangelista, Catherine S Jarnevich, and Melinda Laituri. 2014. "Mapping current and potential distribution of non-native Prosopis juliflora in the Afar region of Ethiopia." *PloS one* 9 (11):e112854.

Wakie, Tewodros T, Melinda Laituri, and Paul H Evangelista. 2016. "Assessing the distribution and impacts of Prosopis juliflora through participatory approaches." *Applied geography* 66:132-143.

WFP, UNICEF. 2009. "Food security and vulnerability in selected towns of Amhara and Afar Regions, Ethiopia." by WFP-Ethiopia -Vulnerability Assessment and Mapping (VAM), Addis Ababa, Ethiopia

Yamane, Taro. 1973. "Statistics: an introductory analysis" a Harper international edition jointly published by Harper & Row, New York, Evanston & London and John Weatherhill, inc., Tokyo.

Yosef, T, U Mengistu, A Solomon, YK Mohammed, and K Kefelegn. 2013. "Camel and cattle population dynamics and livelihood diversification as a response to climate change in pastoral areas of Ethiopia." *Livestock research for rural development* 25 (9):1-10.

Zeila, Abdi. 2011. "Mapping and managing the spread of Prosopis Juliflora in Garissa County, Kenya." Kenyatta University, by Jesuit Historical Institute in Africa (JHIA), http://thesisbank.jhia.ac.ke/id/eprint/1609, Nairobi, Kenya

Zeray, Negussie, Belaineh Legesse, Jema Haji Mohamed, and Mengistu Ketema Aredo. 2017. "Impacts of Prosopis juliflora invasion on livelihoods of pastoral and agro-pastoral households of Dire Dawa Administration, Ethiopia." *Pastoralism* 7 (1):1-14.

ABOUT THE AUTHORS

Ameha T Aytenfisu, (PhD candidate), Center of Food Security Studies, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

Degefa T Degaga, (PhD, Professor of Geography and Development Studies) Center of Rural Development Studies, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

Solomon T Feleke, (PhD), Center for Food Security Studies, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

Desalegn Y Ayal (PhD, Associate Professor), Center for Food Security Studies, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia