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Full Length Article

Relationship between *Prosopis juliflora* invasion and livelihood diversification in the South Afar region, Northeast Ethiopia

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ABSTRACT

This study assessed the effects of *Prosopis juliflora* invasion on livelihood diversification and evaluated the determinants of livelihood diversification in two districts in the South Afar region of Northeast Ethiopia. Using random sampling method, 154 households and 2 focus groups composed of 10 individuals were selected from four sites in the two districts. The relationship between *P. juliflora* invasion and incomes obtained from *P. juliflora* varied across the study sites. In Awash Fentale District and Amibara District, 11.0% and 3.2% of households, respectively, earned income from *P. juliflora* charcoal production. In total, 14.3% of households were involved in charcoal production. In addition, 19.9% of households earned income from selling *P. juliflora* pods and wood materials in the two districts. With the exception of income from *P. juliflora* charcoal production, the sex of households did not affect incomes from other livelihood activities. Moreover, household educational attainment significantly affected income obtained from vegetables, fruits, and cereal crops. Male householders were engaged in more diverse livelihood activities than female householders. Reversing the severe invasion of *P. juliflora* on grazing and woodlands in the region is advisable through integrated natural resources, pastoralist participation, and multidisciplinary research strategies.

1. Introduction

Prosopis juliflora (Sw.) DC. is a shrub or tree native to Central America, Mexico, and Northern America. From its native ranges, *P. juliflora* has spread to Africa, Asia, and Austria primarily through human activities (Pasiecznik et al., 2001). In Africa, *P. juliflora* was first introduced to Senegal in 1822 and, since then, it has been established in Sudan, Eritrea, Egypt, South Africa, and Kenya (Jama and Zeila, 2005). In Ethiopia, *P. juliflora* was first introduced in the 1970s for the reclamation of degraded lowland areas (Abebe, 2012). A research reported by Shiferaw et al. (2019) revealed that 1.20×10^6 ha of invasive *P. juliflora* land cover is expanding at a rate of 3.11×10^4 ha yr^{-1} and currently constitutes 12.3% of the land surface in the Afar region. Pittroff (2019) also reported invasive *P. juliflora* over 1.80×10^6 ha of the Afar region. On the rangelands, *P. juliflora* replaces grasses palatable to livestock, including *Chrysopogon plumulosus*, *Cenchrus ciliaris*, and *Setaria verticillata,* in addition to valuable woody species, such as *Acacia tortilis*, *Acacia senegal*, and *Acacia nilotica* (Dubale, 2008).

Invasive *P. juliflora* in the Afar region of Ethiopia has a serious impact on farmland and grazing land, threatening food security and

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livelihoods (Dubale, 2008; Seid, 2012). Abdulahi et al. (2017) have found that in Gewane District of the Afar region, poorest groups spend more than their entire income as *P. juliflora* associated income, while for medium wealthy population groups, *P. juliflora* associated income accounts on average −25% of all income, which is 10.4% of what the poorest groups lost. However, the invasion of *P. juliflora* has significantly decreased the annual income of agro-pastoral households from livestock and livestock product sales by 28.82% and has increased average annual income from crop sales by 25.85%, although this is not statistically significant (Seid, 2012). In the East Showa and West Arsi zones of the Oromiya region in Ethiopia, *P. juliflora* has a significant impact on crop production, livestock production, biodiversity, and human and animal health (Hundessa and Fufa, 2016).

This study, therefore, sought to: (1) assess the effects of *P. juliflora* on livelihood diversification, and (2) evaluate the determinants of livelihood diversification in the South Afar region of Ethiopia. The study attempted to answer two questions: (1) is there variation in the effects of *P. juliflora* on livelihood diversification in the South Afar region? and (2) do social-related determinant factors affect livelihood diversification in the South Afar region? The results of this study will significantly contribute to the use or eradication of *P. juliflora* in the region.

2. Materials and methods

2.1. Study area

Amibara District (9.19°N, 40.10°E; 741–746 m a.s.l.) and Awash Fentale District (9.10°N, 40.03°E; 700–1000 m a.s.l.) are located in the South Afar region of Northeast Ethiopia. Annual precipitation in Awash Fentale District is 490 mm and in Amibara District is 416 mm. The mean annual temperature for Awash Fentale District is 27.0 °C, the mean minimum annual temperature is 16.7 °C, and the mean maximum annual temperature is 37.8 °C (Fig. 1a). The mean annual temperature of Amibara District is 26.8 °C, the mean minimum annual temperature is 13.8 °C, and the mean maximum annual temperature is 38.2 °C (Fig. 1b). Both districts are located within Ethiopia's lowland agro-ecological zone. *Acacia-Commiphora* woodland and bushlands characterize the region's flora (Friis et al., 2010). Amibara District has a population of 83,851 and Awash Fentale District has a population of 40,901 (CSA, 2013). Ninety percent of Afar people are pastoralists, and the remaining 10% are agro-pastoralists (Wakie et al., 2014).

2.2. Sampling techniques

Secondary data in 2017–2018 were collected from both districts to provide input for primary data collection. Primary data were then collected through focus group discussion, interviews with key informants, and pre-tested semi-structured and structured questionnaires with sampled households. Three-stage sampling methods were used for data collection in each district. Two sites from each district were selected for data collection: Dudub and Kebena in Awash Fentale District and Kurkura and Sidihafage in Amibara District. The status of *P. juliflora* invasion in Dudub and Kurkura was lower than the severe invasion in Kebena and Sidihafage. Therefore, the effects of *P. juliflora* invasion on community livelihoods were compared using sites of low and high invasion in both districts. The districts and sites were selected using systematic sampling of areas with *P. juliflora* invasion. In Awash Fentale District, Dudub comprises 300 households and Kebena comprises 700 households, while in Amibara District, Kurkura comprises 1200 households and Sidihafage comprises 800 households. Sample households were stratified into wealth and sex categories using simple random sampling techniques from total households. Five percent of sample households were selected from each *P. juliflora* invaded site. Households with >10 camels, >20 cattle, and >60 small ruminants (goats and sheep) were categorized as rich. Households with 1–10 camels, 5–10 cattle, and 10–60 small ruminants were categorized as medium households. Households with 0 camel, <5 cattle, and <10 small ruminants were categorized as poor households (Tsegaye et al., 2013).

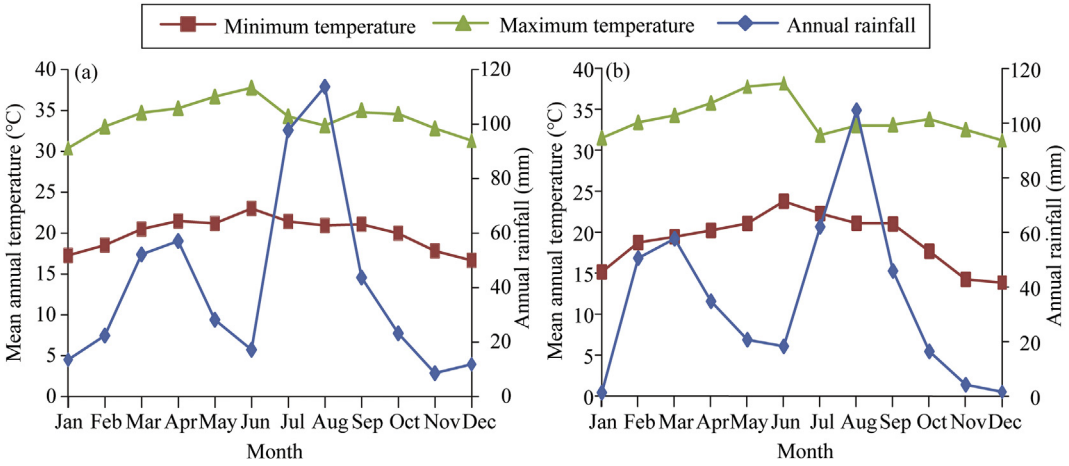

Fig. 1. Thirty-one-year climate diagram for Awash Fentale District (a) and fifteen-year climate diagram for Amibara District (b).

Social perceptions of *P. juliflora* and income sources for livelihood diversification in *P. juliflora* invaded sites were assessed. In total, 154 households were selected using random sampling, and 20 key informants and 10 focus group participants were selected through purposive sampling, comprising a total of 184 research participants.

2.3. Analytical procedure

The study combined qualitative and quantitative data collection and analysis techniques. The data collected were first normalized and then non-parametric Kruskal Wallis tests of K independent samples were conducted. The empirical model for this study is explained in Ojiako et al. (2009):

$$y_i = f(x_1, x_2, \ldots, x_n), \tag{1}$$

where y_i, the dependent variable, is the wealth or socioeconomic status of pastoralists, and x_i ($i = 1, 2, \ldots, n$) is the included explanatory variables. The dependent variable (y_i) is defined as 1 for poor pastoralists, 2 for medium income pastoralists, and 3 for wealthy pastoralists. y_i is also defined as 1 for male and 2 for female pastoralists. In addition to wealth status, other variables initially considered for inclusion in the model included pastoralist, sex, and educational attainment.

In the diversification index, the dependent variable was computed using Simpson's diversification index (SDI) formula:

$$\mathrm{SDI} = 1 - \sum_{i=1}^{n} \left[\frac{Mi}{MT}\right]^2, \tag{2}$$

where *Mi* is the income from each activity, *MT* is the total household income, and *n* is the sources of income.

These indices assumed a value of 0 when their respective upper limit equaled 1 and a value of 1 when their respective upper limit equaled ∞. Proximity to 0 implied decreasing diversification and proximity to 1 implied advancement toward perfect diversification. Explanatory versus response variables were then used for the empirical valuations, using SPSS 24.0 (IBM, 2016).

3. Results

3.1. Prosopis juliflora and livelihood diversification in the South Afar region

Appendix A provides detailed variable measurements and variable definitions. The status of livestock numbers before and after *P. juliflora* invasion was investigated by interviewing key informants (household elders). Cattle, camel, sheep, and goat numbers declined by 56.2%, 48.6%, 25.2%, and 19.4%, respectively (Table 1). In Awash Fentale District, 31.8% of household and, in Amibara District, 61.0% of households earned income from livestock (Fig. 2), while 29.0% of Awash Fentale District households and 41.6% of Amibara District households earned income from the sale of milk. The majority of households, 92.9% and 70.8%, respectively, engaged in livestock and milk selling activities. Furthermore, 19.5%, 20.8%, and 15.6% of households in Awash Fentale District earned income from vegetable, fruit, and cereal crop sales, respectively. Moreover, 11.0% of households in Awash Fentale District and 3.2% of households in Amibara District earned income from *P. juliflora* charcoal production. In total, 14.3% of households were involved in this activity. Meanwhile, 11.0% of households in Awash Fentale District and 22.5% of households in Amibara District earned income from daily labor. In total, 33.5% of households were involved in this activity. A further 19.9% of households earned income from the sale of *P. juliflora* pods and woody materials, the sale of native species woody materials, native species charcoal production, *P. juliflora* fuelwood production, employment, and petty trade.

The results show that 37.0% and 26.0% of households, respectively, engaged in 14 and 15 different income activities and a further 14.9% of households engaged in 8 different income activities (Table 2). In Awash Fentale District, the mean number of activities engaged in by households was 8.1 ranging from 6 to 12 livelihood possibilities. Meanwhile, in Amibara District, the mean number of household income activities was 14.3, ranging from 8 to 16 livelihood options (Table 3).

The mean values for cattle, sheep, goats, and camels sold as sources of individual household income in 2017–2018 were 8.88, 11.45, 15.20, and 4.98, respectively, for Awash Fentale District, and 5.11, 11.55, 16.51, and 3.16, respectively, for Amibara District (Table 4). Moreover, Awash Fentale District had 160.60 L of milk sales in each year and Amibara District had 138.80 L in each year. Households in Awash Fentale District produced 1.25 t of cereal crops (predominantly maize) per year, while there was no record of cereal crops in Amibara District. Meanwhile, 3.03 and 0.26 t of vegetables was recorded for Awash Fentale District and Amibara District in each year, respectively. Awash Fentale District produced 4.26 t of charcoal from *P. juliflora* in each year, and Amibara District produced 0.19 t in

Table 1
Livestock status before and after *P. juliflora* invasion, according to responses of household elder key informants in the South Afar region

Livestock	Number before *P. juliflora* invasion	Number after *P. juliflora* invasion	Difference between after and before *P. juliflora* invasion	Percentage change (%)
Cattle	362	158	204	56.2%
Sheep	377	282	95	25.2%
Goats	412	332	80	19.4%
Camels	214	110	104	48.6%

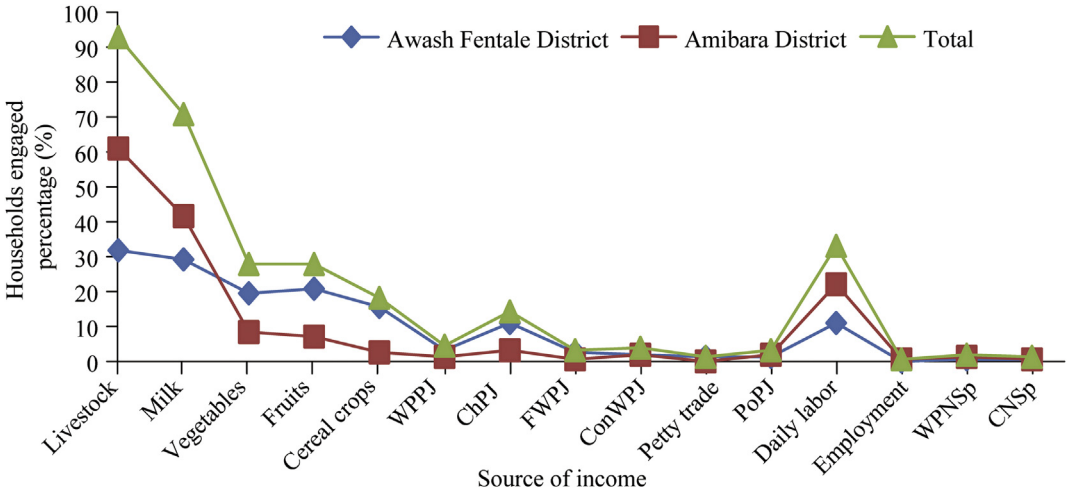

Fig. 2. Household diversification activities in the South Afar region. WPPJ, wood products from *P. juliflora*; ChPJ, charcoal from *P. juliflora*; FWPJ, fuel wood from *P. juliflora*; ConWPJ, construction wood from *P. juliflora*; PoPJ, pods from *P. juliflora*; WPNSp, woody products from native species; CNSp, charcoal from native woody species.

Table 2
Number of household livelihood diversification activities in the South Afar region.

Number of livelihood activities	Frequency	Percentage (%)
6	1	0.6
7	14	9.1
8	23	14.9
9	14	9.1
10	1	0.6
12	1	0.6
13	2	1.3
14	57	37.0
15	40	26.0
16	1	0.6
Total	154	100.0

Table 3
Household livelihood diversification activities in the South Afar region.

District	Mean	SE	Lower	Upper
Awash Fentale	8.1	0.1	6	12
Amibara	14.3	0.1	8	16

Note: SE, standard error of the mean.

each year. In addition, households used certain few quantities of fuel wood and construction wood from *P. juliflora* and native species, and pods from *P. juliflora* in 2017–2018. Moreover, in both districts, off-farm/non-farm income activity strategies, including day labor and petty trade, were used to diversify farming livelihoods.

Data analysis found that SDI for milk, cattle, vegetables, and *P. juliflora* charcoal production were 0.99, 0.90, 0.93, and 0.99, respectively (Table 5). However, the SDI of fruits, cereal crops, *P. juliflora* wood products, *P. juliflora* fuel wood, *P. juliflora* construction wood, *P. juliflora* pods, petty trade, daily labor, native species wood products, and native species charcoal were 1.00. The overall SDI for livelihood options in the South Afar region was 0.80. The overall annual household income of the study area was 1970.68 USD.

3.2. Determinants of livelihood diversification

Income sources such as the sale of milk, vegetables, fruits, cereal crops, and *P. juliflora* charcoal showed significant variation between the two districts (Appendix B). Furthermore, milk, cattle, daily labor, vegetables, fruits, cereal crops, and *P. juliflora* charcoal showed significant variation among the sample sites. In Awash Fentale District, annual incomes earned from the on-farm activities of milk production, cattle, vegetables, fruits, cereal crops, *P. juliflora* wood products, and *P. juliflora* charcoal were 110.91, 154.56, 235.30, 63.99, 46.02, 1.11, and 74.33 USD, respectively (Table 6). In Amibara District, annual incomes obtained from milk production, cattle,

Table 4
Livelihood diversification from farm, off-farm, and non-farm activities in 2017–2018.

Income option	Awash Fentale District		Amibara District	
	Mean	SE	Mean	SE
Cattle (number)	8.88	1.47	5.11	0.70
Sheep (number)	11.45	1.21	11.55	1.33
Goats (number)	15.20	1.84	16.51	1.25
Camels (number)	4.98	1.00	3.16	0.57
Donkeys (number)	0.10	0.08	0.06	0.03
Milk (L)	160.60	1.50	138.80	0.75
Cereal crops (t)	1.25	0.26	0.00	0.00
Vegetables (t)	3.03	0.81	0.26	0.10
Fruits (t)	1.96	0.73	0.03	0.02
Wood products from *P. juliflora* (stack)	0.10	0.04	0.09	0.06
Charcoal from *P. juliflora* (t)	4.26	0.99	0.19	0.09
Fuel wood from *P. juliflora* (stack)	0.08	0.04	0.01	0.01
Construction wood from *P. juliflora* (stack)	0.08	0.05	0.30	0.20
Pod from *P. juiflora* (t)	0.09	0.09	0.16	0.06
Daily labor (d yr^{-1})	4.24	0.95	5.00	0.68
Wood products from native woody species (stack)	4.80	0.05	5.04	0.04
Charcoal from native woody species (t)	0.06	0.06	0.20	0.19

Note: SE, standard error of the mean.

Table 5
Simpson's diversification index (SDI) of livelihood options in the South Afar region in 2017–2018.

Income option	*Mi* (USD yr^{-1})	Share (%)	SDI	SDI range	LoD
Milk	218.46	11.10	0.99	>0.75	Very high
Cattle	624.82	31.60	0.90	>0.75	Very high
Vegetables	514.79	26.10	0.93	>0.75	Very high
Fruits	115.51	5.90	1.00	>0.75	Very high
Cereal crops	121.56	6.20	1.00	>0.75	Very high
Wood products from *P. juliflora*	21.66	1.10	1.00	>0.75	Very high
Charcoal from *P. juliflora*	174.29	8.80	0.99	>0.75	Very high
Fuel wood from *P. juliflora*	0.00	0.00	1.00	>0.75	Very high
Construction wood from *P. juliflora*	0.00	0.00	1.00	>0.75	Very high
Pod/seed from *P. juliflora*	36.97	1.90	1.00	>0.75	Very high
Petty trade	126.12	6.40	1.00	>0.75	Very high
Daily labor	1.59	0.10	1.00	>0.75	Very high
Wood products from native species	6.18	0.30	1.00	>0.75	Very high
Charcoal from native species	8.73	0.40	1.00	>0.75	Very high
Total	1970.68	100.00	0.80	>0.75	Very high

Note: *Mi*, amount of income from each livelihood activity; SDI, Simpson's diversification index; LoD, level of diversification.

Table 6
Annual household incomes from farm, off-farm, and non-farm activities in the South Afar region in 2017–2018.

Sold item	Awash Fentale District					Amibara District				
	Mean (USD yr^{-1})	SE (USD yr^{-1})	Lower (USD yr^{-1})	Upper (USD yr^{-1})	Share (%)	Mean (USD yr^{-1})	SE (USD yr^{-1})	Lower (USD yr^{-1})	Upper (USD yr^{-1})	Share (%)
Milk	110.91	42.40	41.22	212.81	14.40	185.48	34.02	123.39	257.88	9.40
Cattle	154.56	57.25	58.00	281.62	20.00	94.47	13.07	70.93	121.49	3.60
Vegetables	235.30	68.36	123.26	380.16	30.50	7.30	2.71	2.72	13.02	0.70
Fruits	63.99	21.99	26.60	111.88	8.30	0.44	0.44	0.00	1.45	0.10
Cereal crops	46.02	31.07	7.86	116.86	6.00	0.00	0.00	0.00	0.00	0.00
Wood products from *P. juliflora*	1.11	1.08	0.00	3.70	0.10	0.52	0.39	0.00	1.44	0.10
Charcoal from *P. juliflora*	74.53	16.94	41.43	109.00	9.70	2.78	2.80	0.00	9.29	0.80
Petty trade	14.83	10.09	0.00	38.76	1.90	2.59	2.14	0.00	7.49	0.60
Daily labor	68.67	16.01	37.65	100.32	8.90	69.05	10.58	49.16	90.83	2.90
Wood products from native species	1.78	1.75	0.00	5.81	0.20	0.44	0.45	0.00	1.49	0.10
Total	771.71					363.08				

Note: SE, standard error of the mean.

vegetables, fruits, cereal crops, *P. juliflora* wood products, and *P. juliflora* charcoal earned 185.48, 94.47, 7.30, 0.44, 0.00, 0.52, and 2.78 USD, respectively.

Results show that 65% of male householders and 28% of female householders engaged in livestock rearing activity; 51% of male householders and 20% of female householders engaged in milk production related to cattle rearing (Fig. 3). Furthermore, 22% of male householders engaged in vegetables and fruits, 14% of male householders and 4% of female householders engaged in cereal crops, and 12% of male householders and 3% of female householders earned income from the sale of *P. juliflora* charcoal. Meanwhile, 25% of male householders and 8% of female householders earned wages from daily labor.

The annual mean income values for Awash Fentale District and Amibara District were 771.71 and 363.08 USD, respectively (Table 6). In Awash Fentale District, the highest annual incomes were earned from vegetables (235.30 USD), cattle (154.56 USD), and milk (110.91 USD), while, in Amibara District, the highest annual incomes were earned from milk (185.48 USD), cattle (94.47 USD), and daily labor (69.05 USD). In Awash Fentale District, the lowest annual incomes were earned from *P. juliflora* wood products (1.11 USD), native species wood products (1.78 USD), and petty trade (14.83 USD). In Amibara District, 0.44, 0.44, 0.52, 2.59, 2.78, and 7.30 USD were the recorded annual earnings for fruits, native species wood products, *P. juliflora* wood products, petty trade, *P. juliflora* charcoal, and vegetables, respectively.

With the exception of income from *P. juliflora* charcoal production, the sex of households did not affect incomes from livelihood activities (Appendix B). The income earned by male householders for *P. juliflora* charcoal production (35.5 USD yr^{-1}) was higher than that of female householders (6.2 USD yr^{-1}) (Table 7). However, non-significant effects showed that female householders earned higher income (182.1 USD yr^{-1}) than male householders (149.3 USD yr^{-1}) from the sale of milk. In addition, female income from cereal crops sales (34.6 USD yr^{-1}) was higher than male income (7.1 USD yr^{-1}), and female petty trade income (15.7 USD yr^{-1}) was also higher than male income (3.2 USD yr^{-1}). Similarly, the income earned from the sale of native species wood products was higher for females (1.0 USD yr^{-1}) than for males (0.8 USD yr^{-1}). On the other hand, female income from the sale of cattle (79.1 USD yr^{-1}) was lower than male income (129.6 USD yr^{-1}). The overall income earned by female householders (446.6 USD yr^{-1}) was less than that earned by male householders (522.2 USD yr^{-1}) in the South Afar region (Table 7).

Household educational attainment also significantly affected vegetable, fruit, and cereal crop incomes (Appendix B). Incomes from the sale of vegetables were 230.1, 82.0, and 36.3 USD yr^{-1}, for households with post-secondary education, no formal education, and primary education, respectively; while 24.2 and 22.2 USD yr^{-1} was earned from the sale of fruits by households with post-secondary education and no formal education, respectively; and 12.1 and 15.8 USD yr^{-1} was earned from the sale of cereal crops by households with post-secondary and no formal education, respectively (Table 8). Meanwhile, 0.5 and 12.1 USD yr^{-1} was earned from the sale of *P. juliflora* wood products for households with no formal and secondary education, respectively; 26.0 and 96.9 USD yr^{-1} was earned from the sale of *P. juliflora* charcoal by households with no formal education and post-secondary education, respectively; and 7.3 USD yr^{-1} was earned from petty trade by households with no formal education. Respondents with no formal education, secondary education, and post-secondary education earned 66.1, 160.4, and 205.9 USD yr^{-1}, respectively, from daily labor. The overall annual incomes earned by households with no formal education, primary education, secondary education, and post-secondary education were 506.1, 181.7, 210.1, and 748.5 USD, respectively (Table 8).

Household wealth status also significantly affected incomes from cattle, vegetables, cereal crops, and *P. juliflora* charcoal production (Appendix B). Wealthy (227.7 USD yr^{-1}) households earned higher incomes from milk sale than medium (117.7 USD yr^{-1}) or poor (180.3 USD yr^{-1}) households (Table 9). The incomes from the sale of cattle earned by wealthy, medium, and poor households were

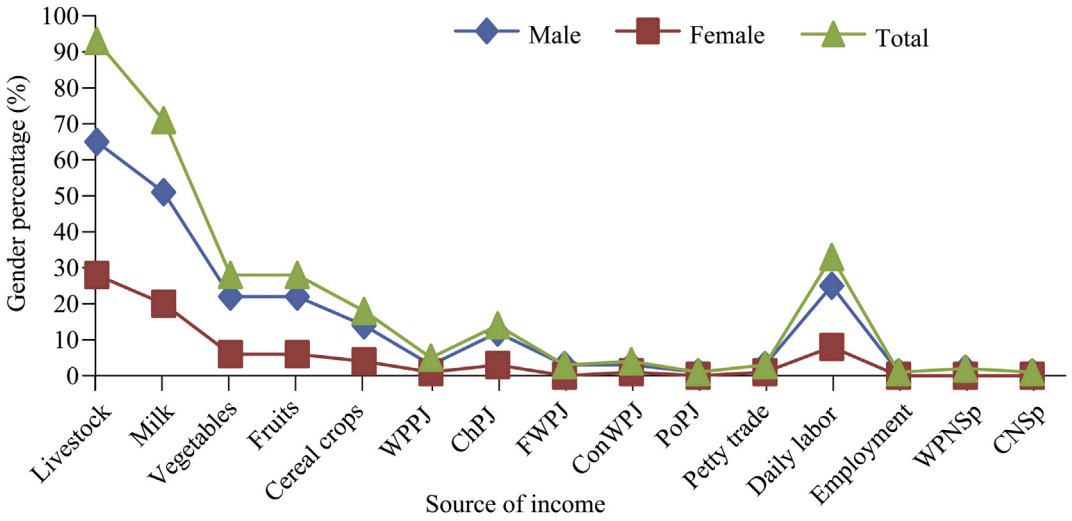

Fig. 3. Male and female diversification activities in the South Afar region. WPPJ, wood products from *P. juliflora*; ChPJ, charcoal from *P. juliflora*; FWPJ, fuel wood from *P. juliflora*; ConWPJ, construction wood from *P. juliflora*; PoPJ, pods from *P. juliflora*; WPNSp, wood products from native species; CNSp, charcoal from native woody species.

Table 7
Annual household farm, off-farm, and non-farm incomes by males and females in the South Afar region in 2017–2018.

Sold item	Annual household income (USD yr^{-1})							
	Male householders				Female householders			
	Mean	SE	Lower	Upper	Mean	SE	Lower	Upper
Milk	149.3	29.3	97.0	212.9	182.1	55.2	94.8	309.1
Cattle	129.6	26.9	81.3	186.9	79.1	18.8	45.8	120.2
Vegetables	93.8	33.0	42.2	164.4	58.7	29.1	12.5	124.3
Fruits	22.6	8.6	8.5	41.9	19.3	15.1	1.6	55.8
Cereal crops	7.1	3.6	2.2	15.4	34.6	33.4	0.0	113.4
Wood products from *P. juliflora*	0.9	0.6	0.0	2.3	0.3	0.3	0.0	1.1
Charcoal from *P. juliflora*	35.5	8.8	19.1	53.6	6.2	6.2	0.0	19.9
Petty trade	3.2	2.2	0.3	8.2	15.7	11.0	0.0	39.8
Daily labor	79.4	11.4	55.4	101.5	49.5	13.7	24.7	78.9
Wood products from native species	0.8	0.8	0.0	2.7	1.0	1.0	0.0	3.2
Total	522.2				446.6			

Note: SE, standard error of the mean.

Table 8
Annual household farm, off-farm, and non-farm incomes by household educational attainment in the South Afar region in 2017–2018.

Sold item	Annual household income (USD yr^{-1})							
	No formal education		Primary education		Secondary education		Post-secondary education	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Milk	168.6	28.1	109.0	83.1	19.4	17.8	58.1	54.5
Cattle	116.7	20.9	36.3	27.7	18.2	17.5	121.1	79.7
Vegetables	82.0	25.6	36.3	27.7	0.0	0.0	230.1	109.0
Fruits	22.2	8.0	0.0	0.0	0.0	0.0	24.2	23.4
Cereal crops	15.8	11.2	0.0	0.0	0.0	0.0	12.1	11.7
Wood products from *P. juliflora*	0.5	0.4	0.0	0.0	12.1	11.1	0.0	0.0
Charcoal from *P. juliflora*	26.0	6.3	0.0	0.0	0.0	0.0	96.9	93.4
Petty trade	7.3	4.0	0.0	0.0	0.0	0.0	0.0	0.0
Daily labor	66.1	8.7	0.0	0.0	160.4	57.6	205.9	96.5
Wood products from native species	0.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Total	506.1		181.7		210.1		748.5	

Note: SE, standard error of the mean.

502.7, 155.0, and 78.9 USD yr^{-1}, respectively. Medium wealthy households earned higher incomes from the sale of vegetables (148.5 USD yr^{-1}), fruits (37.9 USD yr^{-1}), cereal crops (33.3 USD yr^{-1}), *P. juliflora* wood products (1.0 USD yr^{-1}), *P. juliflora* charcoal (51.4 USD yr^{-1}), petty trade (8.4 USD yr^{-1}), and daily labor (83.6 USD yr^{-1}) than poor or wealthy households. In the study sites, only poor households sold native species wood products (1.4 USD yr^{-1}). The overall incomes of poor, medium, and wealthy households were 413.7, 636.9, and 754.6 USD yr^{-1}, respectively, from different livelihood activities (Table 9).

4. Discussion

4.1. The extent of livelihood diversification strategies

In the Afar region of Northeast Ethiopia, harsh conditions have pushed communities into non-agricultural activities, including permanent employment and self-generating income activities from firewood and charcoal making, rope and mat making, petty trade, and salt trade, in order to survive. Wealthy households practice a number of non-farm income-generating activities, including firewood production, charcoal making, and petty trade (Tsegaye et al., 2013). Off-farm employment includes wage labor on private and state farms in vegetable, fruit, cereal crop, and sugarcane production. Non-farm incomes are important for poverty reduction and household welfare. In Awash Fentale District, off-farm and non-farm livelihood activities account for 13% of household incomes, but for only 2% of household incomes in Amibara District. This study found that approximately 16% of household livelihoods are acquired from off/non-farm activities. Mat et al. (2012) have reported that non-farm income contributes 30%–45% to rural household incomes across the developing world. Off/non-farm activities account for less than 37% of rural incomes in Africa (Kotu, 2014) and 33% of rural incomes in West Bengal (Saha and Bahal, 2014).The income of the majority of household respondents was earned from farm activities, including livestock and milk sales. These two activities earn high incomes due to community modes of living. The number of livestock sold by the households of both districts did not vary. Households in Awash Fentale District sold more milk than households in Amibara District. This may be due to greater quantities of milk consumed at home in Amibara District in terms of problems with transporting milk to market (Tsegaye et al., 2013; Teshome et al., 2016). Following livestock and milk sales, the next most common sources of income were vegetable, fruit, and crop sales. Tsegaye et al. (2013) have found that, following the livestock sale, cereal crop production is the

Table 9
Annual household farm, off-farm, and non-farm incomes by wealth status in the South Afar region in 2017–2018.

Sold item	Annual household income (USD yr^{-1})					
	Poor households		Medium households		Wealthy households	
	Mean	SE	Mean	SE	Mean	SE
Milk	180.3	39.9	117.7	25.4	227.7	202.0
Cattle	78.9	21.7	155.0	31.8	502.7	429.7
Vegetables	49.2	18.1	148.5	61.2	0.0	0.0
Fruits	12.3	7.9	37.9	15.7	24.2	22.5
Cereal crops	5.7	3.9	33.3	28.7	0.0	0.0
Wood products from *P. juliflora*	0.6	0.4	1.0	1.0	0.0	0.0
Charcoal from *P. juliflora*	13.6	5.8	51.4	14.9	0.0	0.0
Petty trade	6.3	4.1	8.4	7.3	0.0	0.0
Daily labor	65.3	11.1	83.6	16.2	0.0	0.0
Wood products from native species	1.4	1.0	0.0	0.0	0.0	0.0
Total	413.7		636.9		754.6	

Note: SE, standard error of the mean.

main source of income in the North Afar region. More household income is generated in Awash Fentale District from the sale of *P. juliflora* charcoal production than in Amibara District. This may be due to the proximity of *P. juliflora* sites to main roads, allowing for easier transportation and access to big markets (Chiteculo et al., 2018). In Amibara District, some householders are hired to work on irrigation channel projects and on individual or state farming activities and, therefore, earn more income from wage labor than householders in Awash Fentale District. Mat et al. (2012), Saha and Bahal (2014), Kassie et al. (2017), and others confirmed that off/non-farm activities provide alternative employment for households in different parts of the world.

More than 60% of households had 14 and 15 different sources of income in the South Afar region. This study found a greater variety of income sources than a study by Teshome et al. (2016) in the Afar region. Households in Amibara District were engaged in more livelihood diversification activities than households in Awash Fentale District. This may be due to the different irrigation activities of households engaged in farm, off-farm, and non-farm activities on private and state farms. It may also be due to the higher scope for marketing in the non-farm sector in Amibara District (Saha and Bahal, 2014). Bila et al. (2015) have found that households are pushed into the off-farm sector due to a lack of opportunities and pulled into acquiring incomes from large livestock herds. Deterioration of rangelands due to *P. juliflora* invasion and drought pushes households to choose a more diverse range of livelihood activities (Yassin, 2013). More cereal crops, vegetables, and fruits were produced in Awash Fentale District than in Amibara District. This may be due to variation in the modes of living, with more Amibara District households than Awash Fentale District households specializing in livestock (Tsegaye et al., 2013). In Ethiopia, most agricultural policies emphasize single farm agricultural activities, and neglect the rich opportunities offered by non-agricultural livelihood diversification (Kassie et al., 2017). Based on the findings of Khatun and Roy (2012) and Pujiriyani et al. (2019), the overall level of livelihood diversification of the study area was very high (SDI $>$ 0.75).

4.2. Determinants of livelihood diversification in the South Afar region

Diversification of household livelihood sources varied by district, village, and site. Reasons for the variety in the number of income sources include variations in institutional factors (extension agents), modes of living, availability of irrigation schemes, and lack of agricultural inputs such as fertilizers, money subsides, implements, and seeds (Kassie et al., 2017). Transport facilities and market accessibility could also account for variations in the number of livelihood sources leading to limited household incomes or specialization in single farm activity (Tsegaye et al., 2013).

Livelihood activities showed variety but weak significance between sexes. Male householders were engaged in more diverse livelihood activities than female householders. This may be due to male householders control resources in rural Ethiopia, giving men greater access and opportunities to participate in income diversification (Owitti, 2015; Kassie et al., 2017). More male householders were engaged in cattle, milk, cereal crops, *P. juliflora* charcoal production, and daily labor. Meanwhile, fruits and vegetables were balanced between both sexes, while more female householders participated in petty trade than male householders. This may be because petty trade is carried out in permanent settlements (towns and villages) and male householders are more likely to follow traditional mobile herding livestock husbandry regimes (Tsegaye et al., 2013).

In Awash Fentale District, the sales of vegetable, cattle, and milk make the biggest contribution to household income, while in Amibara District, milk, cattle, and daily wage labor make the biggest contribution to household income. The high contributions made by cattle and milk sales in Awash Fentale District may be due to the mode of living and a favorable market environment. In Amibara District, the existence of state farms with irrigation schemes pushes households to seeking income from daily labor, and the mode of living leads to lower income from milk and cattle sales. Households (head of household) that attained post-secondary education earned more income from the sale of vegetables, while households with no formal education generated more income from cereal crops than educated households. This may be because cereal crops are produced primarily for home consumption and it is more likely that those with no formal education will participate in this form of production. On the other hand, more households with no formal education participated in petty trade than educated households and educated households were more likely to participate in daily labor. Households with no formal education also generated more of their income from native species wood fuel than educated households. The

wealth level of households significantly affected the production of vegetables, cereal crops (maize), and *P. juliflora* charcoal. Medium wealthy households had more income sources than either poor or wealthy households.

5. Conclusions

In both districts, the majority of households acquired incomes from livestock and milk sales. This indicates that most households in the study area specialized in livestock rearing. Households in Awash Fentale District were more aware of using *P. juliflora* than households in Amibara District. Households in Amibara District engaged in more diverse livelihood activities than households in Awash Fentale District. Furthermore, households in Amibara District pushed to secure their incomes from off/non-farm activities in addition to farm activities. The majority of households in Awash Fentale District generated more of their income through farming than the households in Amibara District. However, income from livestock and milk sales did not vary between the two districts, indicating similar modes of livestock rearing as the main livelihood income sources in both districts. Wealth status, gender, and educational attainment of households determined livelihood diversification in the study area.

In South Afar region, lack of control of *P. juliflora* significantly affects the number of cattle due to the loss of natural pasture biomass caused by the displacement of grazing lands. There is a lack of clear policies to deal with the *P. juliflora* invasion, leading to livestock losses in the region. More research on the effects of *P. juliflora* invasion on the biomass of valuable grasses, its impacts on dairy, beef, and cattle production and productivity, is essential. Other associated factors for the decline of livestock numbers after *P. juliflora* invasion should be investigated in order to inform and guide policymakers. Detailed research on the carrying capacity of livestock should be carried out to improve rangeland management and planning. Furthermore, the creation of awareness among local communities should be conducted by all stakeholders so that household heads and their families can more effectively diversify their incomes in order to withstand the effects of drought and climate change in the region.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.regsus.2020.09.002.

Appendix A. Variables definition and measurements

Variable type	Item	Type and definition	Measurement
Treatment variable	Invasion *P. juliflora*	Continuous, number before and after *P. juliflora* invasion	Number
Outcome variable	Income from livestock sales	Continuous, annual income from livestock sales	USD
Outcome variable	Income from cereal crop sales	Continuous, annual income from cereal crop sales	USD
Outcome variable	Income from fruit sales	Continuous, annual income from fruit sales	USD
Outcome variable	Income from vegetable sales	Continuous, annual income from vegetable sales	USD
Outcome variable	Income from petty trade	Continuous, annual income from petty trade	USD
Outcome variable	Income from daily labor	Continuous, annual income from daily labor	USD
Outcome variable	Income from charcoal and wood related sales	Continuous, annual income from charcoal and wood related sales	USD
Outcome variable	Income from milk sales	Continuous, annual income from milk sales	USD
Explanatory variable	Wealth	Ordinal, wealth class of household head	1, poor household; 2, medium household; 3, wealthy household
	Sex	Dummy, sex of household head	1, male household; 2, female household

(*continued on next page*)

(*continued*)

Variable type	Item	Type and definition	Measurement
Explanatory variable			
Explanatory variable	Educational attainment	Ordinal, educational attainment of household head	1, no formal education; 2, primary education; 3, secondary education; 4, post-secondary education
Explanatory variable	Farm, off-farm, and non-farm activities	Dummy, engagement of the household head in farm/off-farm/non-farm activities	1, otherwise; 2, the household head is engaged in farm/off-farm/non-farm activities

Appendix B. Income from livelihood options in the South Afar region

Variable	Statistics index	Income from milk (USD yr^{-1})	Income from cattle (USD yr^{-1})	Income from daily labor (USD yr^{-1})	Income from vegetables (USD yr^{-1})	Income from fruits (USD yr^{-1})	Income from cereal crops (USD yr^{-1})	Income from WPPJ (USD yr^{-1})	Income from ChPJ (USD yr^{-1})	Income from petty trade (USD yr^{-1})	Income from WPNSp (USD yr^{-1})
District	χ^2	5.8	0.1	0.0	35.7	54.9	43.1	0.2	35.3	0.6	0.0
	df	1	1	1	1	1	1	1	1	1	1
	P value	0.016	0.735	0.861	<0.0001	<0.0001	<0.0001	0.655	<0.0001	0.432	0.950
Site	χ^2	46.1	44.5	32.7	79.0	101.1	76.6	1.6	72.2	3.8	0.7
	df	3	3	3	3	3	3	3	3	3	3
	P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.662	<0.0001	0.286	0.879
Sex	χ^2	0.6	2.1	2.6	2.6	0.7	1.7	0.8	4.1	<0.0001	<0.0001
	df	1	1	1	1	1	1	1	1	1	1
	P value	0.424	0.150	0.106	0.110	0.404	0.187	0.359	0.043	0.832	0.882
Educational attainment	χ^2	7.4	5.3	7.9	14.5	14.8	8.6	1.0	3.5	6.9	1.2
	df	3	3	3	3	3	3	3	3	3	3
	P value	0.061	0.154	0.049	0.002	0.002	0.036	0.804	0.317	0.075	0.759
Wealth	χ^2	1.0	9.0	2.5	12.6	5.8	7.7	0.3	8.4	0.6	1.9
	df	2	2	2	2	2	2	2	2	2	2
	P value	0.61	0.01	0.29	<0.0001	0.05	0.02	0.84	0.02	0.75	0.40

Note: *df*, degree of freedom; WPPJ, wood products from *P. juliflora*; ChPJ, charcoal from *P. juliflora*; WPNSp, wood products from native species; 1 USD = 27.52 ETB for 2017–2018.

References

Abdulahi, M.M., Ute, J.A., Regasa, T., 2017. *Prosopis juliflora L:* distribution, impacts and available control methods in Ethiopia. Tropical and Subtropical Agroecosystems 20, 75–89.

Abebe, Y.T., 2012. Ecological and economic dimensions of the paradoxical invasive species-*Prosopis juliflora* and policy challenges in Ethiopia. J. Econ. Sustain. Dev. 3 (8), 62–70.

Bila, Y., Mshelia, B.S., Landi, J.H., 2015. Off farm activities and its contribution to household income in Hawul local government area, Borno State, Nigeria. IOSR J. Agric. Vet. Sci. 8 (10), 9–13.

Chiteculo, V., Lojka, B., Surovy, P., et al., 2018. Value chain of charcoal production and implications for forest degradation: case study of Bie Province, Angola. Environments 5, 113.

CSA, 2013. Population Projection of Ethiopia for All Regions at Woreda Level from 2014–2017, Federal Democratic Republic of Ethiopia.

Dubale, A., 2008. Invasive plants and food security: the case of Prosopis juliflora in the Afar region of Ethiopia, Prepared for IUCN by FARM-Africa. http://cmsdata.iucn.org/downloads/invasive_plants_and_food_security.

Friis, I., Sebsebe, D., Breugel, P.V., 2010. Atlas of potential vegetation of Ethiopia. The royal Danish academy of sciences and letters. Biol. Skr. 58, 1–315.

Hundessa, N., Fufa, A., 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.

Jama, B., Zeila, A., 2005. Agroforestry in the Drylands of Africa: a Call to Action. ICRAF Working Paper – No. 1. World Agroforestry Centre. Nairobi.

Kassie, G.W., Kim, S., Fellizar Jr., F.P., 2017. Determinant factors of livelihood diversification: evidence from Ethiopia. Cogent Social Sciences 3, 1369490.

Khatun, D., Roy, B.C., 2012. Rural livelihood diversification in West Bengal: determinant and constraints. Agric. Econ. Res. Rev. 25 (1), 115–124.

Kotu, B.H., 2014. Explaining the off-farm economy in rural Ethiopia. Int. Inst. Trop. Agric. https://doi.org/10.13140/RG.2.1.2520.5364.

Mat, S.H.C., Jalil, A.Z.A., Harun, M., 2012. Does non-farm income improve the poverty and income inequality among agricultural household in rural Kedah? Procedia Economics and Finance 1, 269–275.

Ojiako, I.A., Manyong, V.M., Ezedinma, C., et al., 2009. Determinants of wealth and socioeconomic status of rural households: an application of multinomial logit model to soybean farmers in Northern Nigeria. J. Soc. Sci. 19 (1), 31–39.

Owitti, O.L., 2015. Gender differences and relations in rural household livelihoods of gog district, anywaa zone, gambella region, south-western Ethiopia. International Journal of Gender and Women's Studies 3 (1), 51–79.

Pasiecznik, N.M., Felker, P., Harris, P.J.C., et al., 2001. The *Prosopis Juliflora – Prosopis Pallida* Complex: A Monograph. HDRA, Coventry, UK, p. 172.

Pittroff, W., 2019. Invasive alien species: the threat to sustainable livelihoods and ecosystems health. In: Policies and Realities-Needs for Environmental Rehabilitation in Ethiopia. 29th Annual Conference of the Biological Society of Ethiopia. May 3–4 2019, pp. 1–58. Addis Ababa, Ethiopia.

Pujiriyani, D.W., Soetarto, E., Santosa, D.A., et al., 2019. Rural hierarchy of prosperity: livelihood diversification and its implications on rurality. Russ. J. Agric. Soc. Econ. Sci. 4 (88), 70–77.

Saha, B., Bahal, R., 2014. Livelihood diversification pattern among the farmers of West Bengal. Econ. Aff. 59 (3), 321–334.

Seid, M.J., 2012. Household perception about *Prosopis juliflora* and its effect on pastoral livelihood diversification strategy: the case of Gewane district in Afar Regional State, Ethiopia. Int. J. Agric. Sci. Res. 2 (3), 21–51.
Shiferaw, H., Schaffner, U., Bewuket, W., et al., 2019. Modeling the current fractional cover of an invasive alien plant and drivers of its invasion in dryland ecosystems. Sci. Rep. 9, 1576.
Teshome, P., Dessalegn, K., Terefe, E., et al., 2016. Study on cattle management and marketing practices in Afar region. Int. J. Livest. Prod. 7 (8), 55–65.
Tsegaye, D., Vedeld, P., Moe, S.R., 2013. Pastoralists and livelihoods: a case study from northern Afar, Ethiopia. J. Arid Environ. 91, 138–146.
Wakie, T.T., Evangelista, P.H., Jarnevich, C.S., et al., 2014. Mapping current and potential distribution of non-native *Prosopis juliflora* in the Afar Region of Ethiopia. PloS One 3 (9), e112854 (11).
Yassin, A.Y., 2013. Livelihood Diversification in Amibara Pastoral Communities of Afar Regional State: Determinants and Challenges. MSc Thesis. Addis Ababa University, Ethiopia.