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Mapping Spatial and Temporal Distributions of P. juliflora (Sw.) Dc in Afar Region, Ethiopia

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Abstract: **In Ethiopia, Invasive Alien Species (IAS) and their related impacts on biodiversity are increasing. The expansion rate of *P. juliflora* (Mesquite) brought economic, social and ecological problems in Afar region. The intension of the present study is to map the spatial and temporal distributions of *P. juliflora* in Afar region, Ethiopia. Mapping the temporal and spatial distributions and quantifying the invaded areas was carried out using geospatial techniques. The results showed that during the period 1985 to 2016, *P. juliflora* expands by 136 km^2 year^{-1}annually. Its trend involves lag phase, astonishing recover after disturbance, and high infestation rate. The results of the study are helpful in making and/or implementing policies and strategies of environmental and biodiversity managements. The study suggests future studies to include ecological triggers of IAS.**

***Keywords*: Afar, Biodiversity, Invasion rate, *P. juliflora*, Geospatial techniques**

I. Introduction

A species' range boundaries may shift in space because of changes in ecological factors and anthropogenic environmental degradations (Holt, 2003; Tessema, 2012; Rai, 2015). Invasive Alien Species (IAS) and their rapid expansion threaten ecosystems and affect the wellbeing of humans. Exotic tree species became the most common type of invasion in which fascinated research attention become increasing. IAS can have entered and established in the environment from outside of their natural habitat (CBD, 2010). Following habitat change, these alien species are considered as the second supreme driving force to change natural biodiversity (IUCN, 2009). They have devastating impacts on native biota, causing decline or even extinctions of native species (Getachew *et al.*, 2012) and negatively affecting ecosystems (Alemayehu, 2006; Van den Berg, 2010). Their negative impact on the economy costs countries billions of dollars in losses to agricultural production (Jama and Zeila, 2005; Yemane, 2007), and some trillion dollars of environmental cost worldwide annually (Pimentel *et al.*, 2000; Berhanu and Tesfaye, 2006; IUCN, 2009; CBD, 2010).

Invasive alien species are a big threat in Ethiopia, showing off particular problems on biodiversity of the country, agricultural lands, rangelands, protected areas, water bodies and roadsides with both economic and ecological problems (Alemayehu, 2006; Berhanu and Tesfaye, 2006; Dubale, 2008; Shetie, 2008; Girma *et al.*, 2011; Yibekal, 2012; Wakie *et al.*, 2014). *Prosopis juliflora* (Mesquite) is one of the world's top 100 invasive alien species (IUCN, 2009). It has been identified by the Environmental Policy and National Biodiversity Strategy and Action Plan as a major threat to the economy and biodiversity in Ethiopia. (Taye *et al.*, 2012). It belongs to the family Fabaceae subfamily Mimosoideae, and genus Prosopis. *P. juliflora* was introduced to Ethiopia in 1970s (Alemayehu, 2006).

There is insufficient information regarding the expansion of *P. juliflora*, (Witt, 2010) and a very limited attempt has been given to map its distribution in Ethiopia (Akasaka, 2012; Wakie *et al.*, 2014) which arise from lack of resources for conducting research and data collection. Ground surveys and mapping activities is time consuming and too costly for analyzing the invasion rate of *P. juliflora* (Haregeweyn *et al.*, 2013; Pasha *et al.*, 2014; Wakie *et al.*, 2014). Besides, geospatial techniques, which employed advanced Geographic Information System (GIS) and Remote Sensing (RS) are cost and time effective (Haregeweyn *et al.*, 2013; Pasha *et al.*, 2014; Wakie *et al.*, 2014). In this regard, geospatial techniques are useful approaches to map the distributions of IAS, analyze their infestation rate, and the associated patch dynamics (ESRI, 2011; Zeila, 2011; ERDAS, 2014). Although the use of geospatial techniques is crucial to study the history of invasion pattern in large spatial scale and long temporal contexts, a very limited studies with limited spatial scale (Haregeweyn *et al.*, 2013; Wakie *et al.*, 2014) have been shown in Afar region of Ethiopia. Also, quantitative assessments of *P. juliflora* distribution with respect to long temporal contexts has not been clearly conducted.

The investigation of spatiotemporal (space and time) dynamics of IAS in large spatial scale and long temporal context is crucial to provide input for developing economically cost effective and environmentally desirable control methods. Such studies provide baseline data to policy and strategy manners; help monitor, control and/or manage the spread of *P. juliflora* in Afar region, Ethiopia. Therefore, overall objective of the study is to map and analyze the expansion rate of *P. juliflora* in Afar region of Ethiopia for appropriate management decisions. To this end, specific objectives that addressed in this paper include: (i) map spatiotemporal distribution of *P. juliflora* using geospatial techniques; and (ii) quantify spatial and temporal invasion rate of *P. juliflora* in Afar, Ethiopia.

II. METHODOLOGY

The Study Area

The study site is located in the Afar regional state, northern Ethiopia between (8^0 51'0'' and 14^0 34' 0'') N and (39^0 47' 0'' and 42^0 24' 0'') E (Figure 1). The region is one of the nine administrative regions in Ethiopia (WAS, 2008). It is located within the *kola* (arid to semi-arid) and the *Bereha* (desert) agro-ecological area of Ethiopia. The altitude of the region ranges from 1500 m a. s. l. and 120 m b. s. l. The production system of Afar region is dominated by pastoralism (90%). The ecology in the area is fragile with an increasing trend of natural resources degradation (ANRS, 2010).

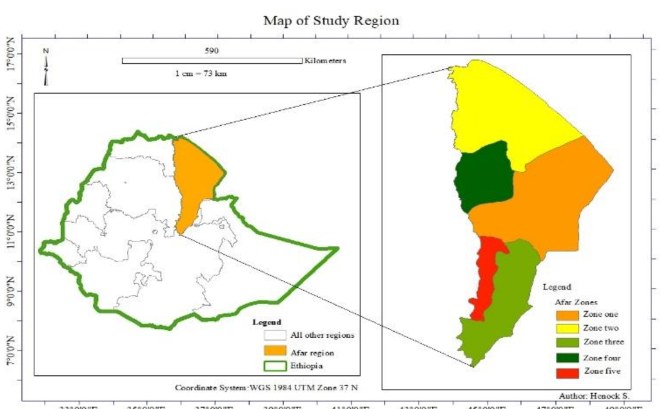


Fig. 1: Map of Afar region showing study zones

Afar National Regional State (ARS) is characterized by arid and semi-arid climate with low and erratic rainfall. Temperatures vary from 20 ºC in higher elevations to 48 ºC in lower elevations in Afar. Rainfall ranges throughout the region with a mean annual rainfall below 500 mm in the semi-arid western escarpments and decreasing to 150 mm in arid zones to the east (EMA, 2012). Afar is increasingly drought prone Rainfall pattern is changing from time to time and temperature generally increasing. Average maximum temperature in Ethiopia has been increasing by 0.1 ºC per decade Such variability in the climate is exposing people to risks of several climate related disasters (EMA, 2012).

Including *P. juliflora* as a major factor, native vegetation consists of grasses, forbs, shrubs, and woody plants are adapted to the arid and semi-arid Afar. Chrysopogon, Sporobolus, Dactyloctenium, Cymbopogon and Cynodon species are dominant herbaceous vegetation (Abule *et al.*, 2007). Woody vegetation is mainly composed of *Senegalia, Senegal, Vachellia. nubica, V. nilotica, V tortilis, V. mellifera* (Tikssa *et al.,* 2010). In addition to livestock, the native plants also provide grazing and foraging uses to wildlife found in the region. The region contains two national parks (Awash and Yangudi-Rassa), three wildlife reserves (Awash West, Alledeghi, and Mille-Serdo), three controlled hunting areas (Gilen Hertalie, Chifra, and Telalak-Dewe), and one open hunting area (Gelila Dura). The parks and wildlife reserves are homes to unique wildlife species of Afar including endangered Grevy's zebra (*E. quusgrevyi*), and critically endangered wild ass (*E. africanus*) (ANRS, 2010).

A. Types of Data

Different categories of *P. juliflora* infested areas have been surveyed during two round field visits. In addition, long term satellite imageries, topographic maps, and aerial photos are involved to collect *P. juliflora* occurrence data. Landsat Thematic Mapper (Landsat TM) images of 1985, 1995, 2008, and 2016 was obtained from United States Geological Survey (USGS) database server. The data have been applied to generate land cover changes associated with *P. juliflora* decadal expansions and to perform species specific spatial analysis using geospatial techniques. The imageries for the study were selected with minimal cloud cover <20 pixels at World Geodetic System 1984 (WGS 1984) UTM Zone 37^0 N coordinate system.

B. Spatial Data Sampling

Covering the whole region during field visits were inapplicable regarding time and cost. Thus, satellite data was incorporated with field data. The five-administrative zone categories have been considered as data points to see the differences in level of invasion and to ease statistical analysis. First round field visit was applied to collect a total of four hundred samples from 100 plots (100 m^2) using stratified random sampling method. The samples were collected from four (25 m^2) quadrats of 20 m transect interval from each plot in January 2016. The data were then applied to train the sub-pixel classifier tool in Erdas Imagine spatial software in that Mesquite coverage estimates were derived. In addition, a total of three hundred random points of Ground Control Points (GCPs) was sampled during second round field visit in February 2016. This was to assess the accuracy of classification. The study performed supervised, non-parametric spectral detection and quantification for a specific Material of Interest (MOI) at a sub-pixel, (30 m x 30 m) level (Zeila, 2011; ERDAS, 2014.

C. Spatial Data Analysis

This study first applied data preparation and field survey preceding to both unsupervised and supervised classification with greater emphasis placed on supervised MOI classification. Invaded areas in each site have been assessed and mapped using geospatial techniques. The procedures include classify, delineate, and digitize boundaries for key invaded areas. Following MOI classification, analyzing *P. juliflora* temporal expansion trend (1985-2016) and mapping its spatial distribution has been taken place in two different phases.

Phase (1) involves assessing total net area under each zone, and analyzing invasion cover change among three decades that include from 1985 to 1995, from 1995 to 2008, and from 2008 to 2016. Invasion cover change map from 1985 to 2016 with reference to *P. juliflora* occurrence also included in this data analysis phase. Spatial procedures applied in the study follows standard image processing techniques. Phase-I includes two further processing stages. Phase-I (A) started from browsing and downloading satellite tilt images by using paths and rows covering Afar region from USGS database server. All scenes were radiometrically calibrated, converted to top of atmospheric reflectance images, corrected for topographic clarification, and temporally normalized between scenes, and cloud as well as shadow masked.

Then, mosaicking images or make one single satellite image covering the region was undertaken in that stacking of three important bands are considered. Band 4, band 3, and band 2 represent spectral signature for red, green, and blue respectively (RGB). The process is then continued with stacking and cutting out portion of the study region to ease the process. In all of 1985, 1995, 2008, and 2016 satellite images outputs, the study followed the processes in similar fashion from which change detection analysis and rate of invasion would have been carried out. Thirdly, quality assurance and artefact removal made the subjected satellite data free from different noise errors. In addition, pre-process to identify potential spectral backgrounds, environmental correction, and signature derivation have been conducted. To accomplish sub-pixel image classification analysis, the study imputed field GCPs to train true image signature of the Mesquite tree.

Moreover, MOI classification successfully obtained for single species classification analysis (Zeila, 2011; ERDAS, 2014). GPS points of field samples were used to locate specific areas to determine the approximate percent coverage for each target MOI. Automatic signature derivation, which takes all training pixels for a specific MOI and evaluates them for a common composition of spectral measurements was used to produce initial signatures. Multiple classifications were run for MOI on the selected image by varying spectral criteria of 90 % confidence level of acceptable standard error (ERDAS, 2014). All classification runs were compared to ground data and evaluated the strongest (most accurate) run for MOI was then selected and used for further data analysis (Zeila, 2011; ERDAS, 2014).

To test accuracy of classification process, the study applied confusion matrix approaches (Foody, 2002; ESRI, 2011; Haregeweyn *et al.,* 2013; Pasha *et al.,* 2014). Quantitative assessment of the accuracy of mapping for mesquite classification and covers was undertaken on the classified map and verified in the field. This was determined by percent relationship between *P. juliflora* presences observed in the field and that of classified based on visual image interpretation technique in an error matrix. Independently following same procedure defined above, the classification output raster layers for all of the consecutive decades were sequentially exported to ESRI 10.5 ArcMap software. The study reclassified and masked ‘present’ and ‘absent’ of *P. juliflora* occurrence. Then converted out to ESRI shape files, and combined rasterized recoded shape files of the administrative divisions (i.e., zone) have been performed to get the estimated areal coverage of Mesquite for 1985, 1995, 2008, and 2016. The outputs of shape file and statistical summaries are applied in phase-II for further analysis of invasion rate.

In phase -I (B), the RS techniques in Erdas imagine software allows the study to apply image difference analysis process after passing bunch of aforementioned geospatial image processes. This sub-phase involves temporal change detection analysis in each administrative division in Afar based on species specific MOI results. Accordingly, *P. juliflora* cover of multiple classification output presented by percent patch levels during 1985 to 1995, 1995 to 2008, 2008 to 2016, and 1985 to 2016 analysis intervals. The image difference analysis was conducted by considering more than 10% changes. The output result then, converted to shape files. Finally, statistical estimation was conducted by administrative boundaries of vectorized image of the region. All the spatial analysis phases of the study finally incorporated statistical summaries.

In phase (2), identifying and quantifying the spreading rate of *P. juliflora* have been estimated. Phase-II mainly involves the annual rate of *P. juliflora* invasion cover change in Afar region and it was derived using total invaded area over total time (Davis *et al.,* 2000; Haregeweyne *et al.,* 2013; Pasha *et al.,* 2014). This was applied to present the invasion rate by unit area per time (Km^2 $Year^{-1}$). Statistical techniques are applied almost in all of data analysis phases in the study. Mapping and quantifying the invasion trends was carried out following each spatial analysis output of the preceding phases.

The intuitive nature of the spatial analysis in RS techniques to distinguish species specific (MOI) land classification and map the spatial variations alongside GIS spatial analysis approach allowed the study to identify and map *P. juliflora* spread in the whole Afar region with time and space regards. In addition, the quality of these geospatial approaches helps the study carry out *P. juliflora* invasion rate in the administrative divisions of the study area.

III. Results and Discussion

The quantifications of *P. juliflora* (Mesquite) area cover was estimated and summarized for more than three consecutive decades. In addition, the estimation of annual invasion rate of Mesquite for each time intervals have been successfully accomplished (Tables: 1 and 2).

TABLE 1
Summary of *P. juliflora* temporal invasion rate

No.	Year	Total invaded area (Km^2)	Invasion rate	
			$Km^2 Year^{-1}$	%
1.	1985-1995	3412.20	341.22	4.74
2.	1995-2008	1375.69	106.52	1.91
3.	2008-2016	2634.29	329.28	3.67
4.	1985-2016	4192.34	136.00	5.82

Invasion Rate of P. juliflora (Sw.) DC

Expansion trends of *P. juliflora* was summarized for Afar region in the course of thirty-one year which point out its spatial increases during 1985-1995 with total annual area of 341.22 km^2 $year^{-1}$ (Table 1). During this period, zone one presented the highest invasion rate that reached 109.80 km^2 $year^{-1}$ followed by zone three with 80.63 km^2 $year^{-1}$ annual invasion rate. The lowest invasion rate during 1985 to 1995 showed in zone two with 9.66 km^2 $year^{-1}$ (Appendix Table 1). In addition, *P. juliflora* exhibited 4.74% expansion rate out of total area of the region (Table 1) from 1985 to 1995. Similarly, the woody mesquite expansion rate revealed its high distributions (568.7 km^2 of total average area cover) during this interval with zone one presented the highest patch (Appendix Table 2). High distribution of Mesquite during 1985 to 1995 may indicate its lag phase or spreading feature considering its introduction to Ethiopia in 1970s (Almayehu, 2006). The lag time between the phases of such IAS can range from decades to a century as described by Erneberg (2002). Climatic fluctuations like drought or anthropogenic disturbance like over grazing may exacerbate these boom of *P. juliflora.*

Beside this, *P. juliflora* distribution presented decreasing manner during 1995-2008. It was identified as 1.91 % of the total area of the study region (Table 1). The administrative zones also exhibited similar trends for Mesquite decrements. For example, the lowest total distribution of *P. juliflora* was presented in zone two (9.66 km^2 $year^{-1}$) during 1985-1995 became decreased to 44.97 km^2 $year^{-1}$ in 1995-2008. Similarly, all five administrative zones shown reducing trend in the second analysis period of the study (Appendix Table 1). Again, the largest invaded area is still exhibited in zone one and in zone three while it shows general declining temporal trends relative to the 1985-1995 analysis year.

In addition, it also shows similar trend for the maximum patch in each zone again. For example, zone one which has had highest patch during the first analysis year interval (1985 to 1995) changed from 527.40 km^2 to 145.73 km^2 (Appendix Table 2) with 109.80 km^2 $year^{-1}$ of annual invasion rate in 1995-2008. Out of the total invaded area in the second analysis year, 42.49% and 40.41% *P. juliflora* cover were in zone one and zone two respectively (Appendix Table 2). In addition, the trends of maximum average patch shown initially increasing trend in (1985-1995) then decreasing in 1995-2008 (Figure 2 and Appendix Table 2).

APPENDIX TABLE 1
Summary statistics for spatial and temporal invasion rate of *P. juliflora*

No.	Year interval	Administrative Zone	Decadal invasion change (Km^2)	Annual invasion rate ($Km^2 Year^{-1}$)
1.	1985-1995	Unknown	684.46	68.45
		Zone one	1097.97	109.80
		Zone two	96.55	9.66
		Zone three	806.35	80.63
		Zone four	213.44	21.34
		Zone five	513.43	51.34
	Total		3412.22	341.22
2.	1995-2008	Unknown	17.51	1.35
		Zone one	584.56	44.97
		Zone two	29.88	2.99
		Zone three	555.73	42.75
		Zone four	117.00	9.00
		Zone five	71.01	5.46
	Total		1375.69	106.52
3.	2008-2016	Unknown	185.36	23.17
		Zone one	425.54	53.19
		Zone two	530.96	66.37
		Zone three	752.45	94.06
		Zone four	520.35	65.04
		Zone five	219.63	27.45
	Total		2634.29	329.28

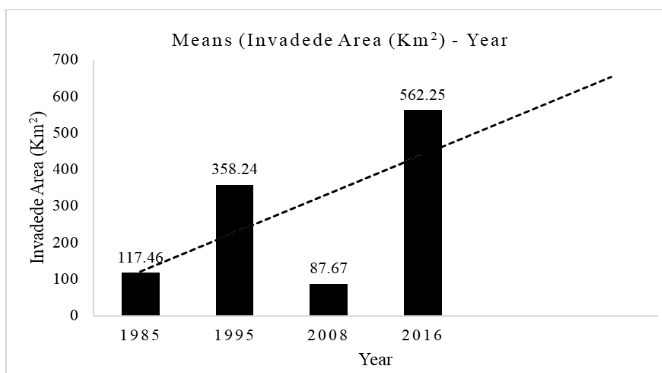


Fig. 2: Trends of total average invaded area

The possible reason for Mesquite decrements during 1995-2008 period may be a result of eradication activity in the region by FARM-Africa, and USAID supported Pastoral Livelihoods Initiative (PLI) under CARE Ethiopia consortium (FARM-Africa, 2009) as IAS control measure. Or it may be due to their attempt to establish economic activities all over the Afar region. The efforts were put to control the spread of Mesquite through eradication measure which included clearing the woody weed for charcoal market, and also reclaiming the cleared land for crop and pasture production. Although, the approaches by that time brought decline the spread status dramatically, it returned intensely by the consecutive years with 329.28 Km^2 $year^{-1}$ (Table 1). The study is in line with, Haregeweyn *et al.* (2013) regarding the decreasing trends of mesquite during 1995-2008.

TABLE 2
Summary of *P. juliflora* spatial expansion rate in Afar during 1985-2016

No.	Administrative division	Total invasion (Km^2)	Expansion rate (Km^2Year^{-1})	Expansion rate (%)
1.	Unknown	78.55	3	2
2.	Zone one	1105.73	36	26
3.	Zone two	685.99	22	16
4.	Zone three	1213.84	39	30
5.	Zone four	764.95	25	18
6.	Zone five	343.29	11	8
	Total	4192.34	136	100

During 2008-2016, the study region was under increasing *P. juliflora* infestation patterns again. The reinvasion trend was increasing common to all zones of the study region relative to the previous decade. Comparing to the previous period (1995-2008), it is dramatic that reinvasion of Mesquite and large areas of the study region converted to *P. juliflora* (Appendix Table 1). Almost 3.67% of the total area of Afar region (Table 1) with 229.28 km^2 total average invaded area was estimated from 2008 to 2016 (Figure 2 and Appendix Table 2). Zone three has the highest rate with 94.06 km^2 $year^{-1}$, followed by zone four of 65.04 km^2 $year^{-1}$ which can indicate the invasion rate of *P. juliflora* is expanded to more new areas than its spatial extent of the previous decades (Appendix Table 1). Moreover, about 66.37 km^2 $year^{-1}$, 53.19 km^2 $year^{-1}$, and 27.45 km^2 $year^{-1}$ of *P. juliflora* expansions continued in zone two, zone one, and zone five of remaining administrative divisions of the study region respectively between 2008 to 2016. This indicates both temporal and spatial trends of Mesquite weed distributions is expanding in the region (Appendix Table 1). This may have related to the dispersal ability of Mesquite particularly after eradication measure in that the intervention might facilitate seed dispersal opportunity to regenerate and expand to new areas. In addition, the possible reason to such expansion to new areas may be related to ecological drivers like temperature fluctuations. The woody invasive plant might move towards in favor of climatic fluctuations together with soil properties like pH. Ecological drivers can trigger such rapid spatial expansion trends (Van den Berg, 2010; Pasha *et al.*, 2014). The situation is more pronounced especially in areas where frequent drought occurs like Afar region where recurrent drought occurs. Maximum temperature is increasing in the recent decades, and there is fluctuating precipitation patterns in the region (EMA, 2012). Furthermore, *P. juliflora* seed germination has been described to show covariance with temperature and soil chemical property ranges in dryland ecosystems (El-Keblawy and Al-Rawai, 2005). In general, quantification of spatial and temporal expansion of *P. juliflora* shows high takeoff in the entire region initially followed by decreasing trend regionally including both within and among administrative divisions. Eventually, it increases back into its high invasion feature.

Mapping Spatial Distribution of P. juliflora (Sw.) DC in Afar Region

During the period of analysis from 1985 to 2016, 5.82% of total area of the region is converted to *P. juliflora*. In addition, the change detection map (Figure 3) and the quantification analysis results indicate that *P. juliflora* expands by 136 km^2 $year^{-1}$ annually during 1985 to 2016 (Tables; 1 and 2). Moreover, mapping *P. juliflora* cover shows about 4192.34 km^2 of the region is covered by *P. juliflora.* Identifying the patterns of invasion revealed that there is a similar spatial expansion trends of the woody weed *P. juliflora* almost in all of the administrative divisions from 1985 to 2016 Spatial analysis of the study indicates *P. juliflora* cover was highly distributed with more than 50% of the total invasion presented in zone three and zone one followed by moderate spread with 34 % in zone four and zone two, as well as relatively minimal spreads with 10% in zone five and other areas (Table 2). The distribution of Mesquite was in such a way that high patch launches, re-invasions after disturbance, and high spatial expansion trends have been observed. In general, *P. juliflora* expansion shown such trends across all of the five administrative sites in the study region. Zone three shown highest temporal and spatial expansion trends with 30% of total invaded area followed by zone one with 26% of total invaded area in the course of 1985 to 2016 (Table 2).

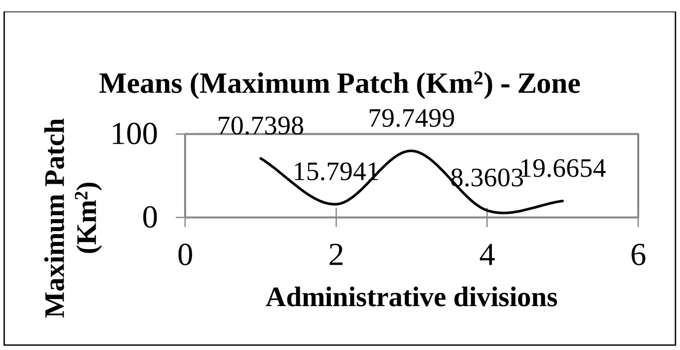
Among Mesquite maximum patches, zone three represents highest ranges over the 1985 and 2016 years. Whereas zone one exhibited the highest maximum patches in 1995 and in 2008 (Figure 4). The patterns of *P. juliflora* distributions might be influenced by different driving factors. Beside this, ability of woody invasive plant to withstand disturbance and high seed dispersal advantages particularly during such eradication actions taken during 1995-2008 analysis year might have resulted the ease of regeneration in short period of time between 2008-2016.

APPENDIX TABLE 2

Summary statistics for temporal *P. juliflora* distributions (km^2)

No.	Year	Zone*	Frequency	Total	Mean	Minimum	Maximum	Std.	Percent (%)
1.	1985-1995								
		UN	2333	684.46	0.2934	0.0005	362.86	8.26	20
		01	221140	1097.97	0.0050	0.0005	527.40	1.13	32
		02	95395	96.55	0.0010	0.0005	0.47	0.00	2.83
		03	257003	806.35	0.0031	0.0005	69.66	0.18	23.63
		04	90242	213.44	0.0024	0.0005	37.05	0.13	6.25
		05	156706	513.43	0.0033	0.0005	12.59	0.07	15.05
Total				3412.20	0.3081	0.0031	1010.03		100
Average				568.70		0.0031	168.49		
2.	1995-2008								
		UN	794	17.51	0.0221	0.0006	10.24	0.37	1.27
		01	127677	584.56	0.0046	0.0006	145.73	0.41	42.49
		02	30284	29.88	0.0010	0.0006	0.16	0.00	2.17
		03	152810	555.73	0.0036	0.0006	32.21	0.13	40.40
		04	58594	117.00	0.0020	0.0006	3.16	0.02	8.50
		05	32811	71.01	0.0022	0.0006	9.12	0.05	5.62
Total				1375.69	0.0354	0.0035	200.62		100
Average				229.28		0.0006	33.44		
3.	2008-2016								
		UN	2134	185.36	0.0869	0.0006	44.82	1.28	7.04
		01	142723	425.54	0.0030	0.0006	12.34	0.05	16.15
		02	272553	530.96	0.0019	0.0006	2.79	0.01	20.16
		03	143858	752.45	0.0052	0.0006	67.98	0.27	28.56
		04	144610	520.35	0.0036	0.0006	10.72	0.06	19.75
		05	64804	219.63	0.0034	0.0006	10.96	0.06	8.34
Total				2634.29	0.1040	0.0035	149.60		100
Average				439.05		0.0006	24.93		

Note: * administrative divisions: UN: unknown area, 01: Zone one, 02: Zone two, 03: Zone three, 04: Zone four, 05: Zone five, std: standard deviation



Note: 1: Zone one, 2: Zone two, 3: Zone three, 4: Zone four, 5: Zone five

Fig. 2: Spatial distribution of maximum *P. juliflora* patch during 1985 to 2016

In addition, the susceptibility of the dryland ecosystem to invasion in Afar might be increased with disturbance whether natural or anthropogenic phenomenon occurred. This might be due to lack of natural competing species from native plants due to biodiversity loss that opportune the woody tree to take advantage of available resources to boom again after disturbance. Disturbance and human and/or livestock movements (Van den Berg, 2010), extreme environmental events such as the rising of maximum temperature or frequent drought may enhance the distributions of Mesquite. The role of environment that favor IAS was described by different authors (Davis *et al.*, 2000; Dubale, 2008; Girma *et al.*, 2011). The high germination nature of the seed, mechanisms of seed dispersal, its physiological ability (adaption to new

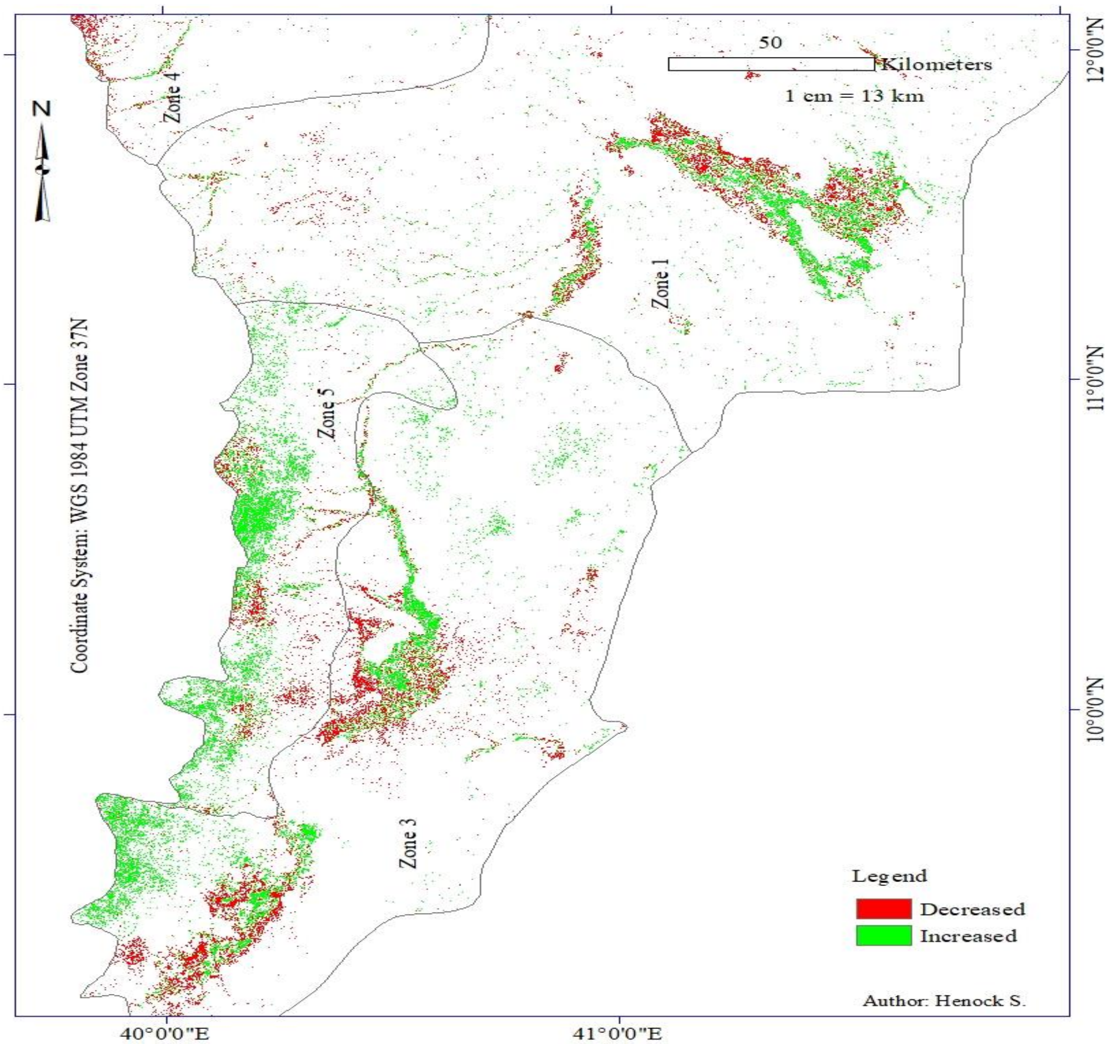


Fig. 3: Spatial distribution of *P. juliflora* in Afar from 1985 to 2016

conditions), and ability to continue on different environmental situations defined such IAS like *P. juliflora* (CBD, 2010). Clear investigations of temporal and spatial maximum patch distribution are crucial to bring a baseline data to the study region for monitoring invasion trends of *P. juliflora.*

IV. CONCLUSIONS

The present study marked out invasion rate of *P. juliflora* high patch start with high invasion rate, following reduction, and finally high expansion pattern with fast recover during its thirty-one years (1985-2016) of invasion history in the whole Afar region, Ethiopia. In addition, it exhibited similar trends of both spatial and temporal spreading out in all of the administrative division of Afar. Determining the rate of IAS with spatial and temporal perspective will be crucial to develop appropriate management measures. The study suggests further study should consider ecological factors triggering the rate of IAS with spatial and temporal perspective.

V. REFERENCES

Abule, E., Snyman, H.A. and Smit, G.N., 2007. Rangeland evaluation in the middle Awash valley of Ethiopia: I. Herbaceous vegetation cover. *Journal of Arid Environments*, 70(2), pp.253-271.

Akasaka, M. 2012. Invasive non-native species attributes and invasion extent: examining the importance of grain size. J. Veg. Sci. 23: 33–40.

Alemayehu, E. 2006. Irrigation management and institutional arrangement: The case of two irrigation scheme, Northeast Ethiopia. MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia.

ANRS (Afar National Regional State). 2010. Assessment of Afar National Regional State for Climate Change Adaptation. Afar National Regional State for Climate Change Adaptation Programme, Semera, Ethiopia.

Berhanu, A. and Tesfaye, G. 2006. The Prosopis dilemma, impact on dryland biodiversity and some controlling methods. Journal of Dryland. 1(2):158-164.

CBD 2010. [http://www.cbd.int/invasive. Accessed 15 Feb 2012.]

Davis, J. Mark A., Philip Grime and Ken Thompson. 2000. Fluctuating Resources in Plant Communities: General Theory of Invasibility. Ecology 2000, 88, 528-534.

Dubale, A. 2008. Invasive Plants and Food Security: the case of Prosopis juliflora in the Afar region of Ethiopia Publication., from IUCN.

El-Keblawy, A. and Al-Rawai, A., 2005. Effects of salinity, temperature and light on germination of invasive Prosopis juliflora (Sw.) DC. Arid Environments, 61(4), pp.555-565.

EMA, 2012. Ethiopian Metrological Agency [http://www.ethiomet. Gov.et.] Accessed: 2016.6.12

ERDAS, 2014. Hexagon Geospatial Product Features and Comparisons: Erdas Imagine 2014 Release Geospatial. [http://www.hexagon.com]. Accessed: 3.1. 2015

Erneberg, M. 2002. The process of plant invasion with focus on the effects of plant disease. PhD thesis. National Environmental Research Institute, Silkeborg, Denmark. 133 pp.

ESRI, 2011 ESRI Redlands (Ed.), ArcGIS Desktop: Release 10, Environmental Systems Research Institute, CA.

FARM-Africa.2007. A livelihood baseline survey in Amibara and Gewane weredas of Afar region. Dynamic Institute for Consultancy and Training. Final Report, p 121.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote sensing of environment, 80(1), pp.185-201.

Getachew S, Demissew S. and Woldemariam T. 2012. Allelopathic effects of the invasive Prosopis juliflora (Sw.) DC. On selected native plant species in Middle Awash, Southern Afar.

Girma, M., Urge, M., & Animut, G. 2011. Ground Prosopis juliflora Pods as Feed Ingredient in Poultry Diet: Effects on Growth and Carcass Characteristics of Broilers. International Journal of Poultry Science, 10(12), 970-976.

Haregeweyn, N., Tsunekawa, A., Tsubo, M., & Meshesha D. 2013. Analysis of the invasion rate, impacts and control measures of Prosopis juliflora: a case study of Amibara District, Eastern Ethiopia. Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan. Environment Assess 185:7527–7542. DOI 10.1007/s10661.

Holt, R.D. 2003. On the Evolutionary Ecology of Species' Ranges. Evolutionary Ecology Research, 2003, 5: 159–178. Department of Zoology, University of Florida, [https://people.clas.ufl.edu/rdholt/files/126.pdf] Accessed: 26 Jun. 2017.

IUCN (International Union for Conservation of Nature).2009 Guidelines on Biofuels and Invasive Species. Gland, Switzerland: IUCN. 20pp.

Jama, B., and Zeila, A.2005. Agroforestry in the drylands of eastern Africa: a call to action (ICRAF Working Paper No. 1). Nairobi, Kenya. (W. A. Centre)

Pasha, Vazeed, K V Satish1, C Sudhakar Reddy, P V V Prasada Rao and C S Jha. 2014. Satellite image based quantification of invasion and patch dynamics of mesquite (Prosopis juliflora) in Great Rannof Kachchh, Kachchh Biosphere Reserve, and Gujarat, India. Indian Academy of Sciences, 123: 1481–1490.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D., 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience, 50(1), pp.53-65.

Shetie Gatew Mitiku. 2008. The Ecological Distribution and Socio-Economic impacts of Prosopis juliflora (Sw.) DC. in the Amibara Woreda, Afar National Regional State. Faculty of Science, Environmental Program, Addis Ababa University.

Taye Tessema, Christian Ulrichs and Carmen Buettner. 2012. Invasive Alien Plant Species in Ethiopia: Impacts, Challenges and Responses: Ethiopian Institute of Agricultural Research Faculty of Agriculture, Humboldt University of Berlin, Lentzealee 55/57 14195 Berlin, Germany.

Tikssa, M., Bekele, T. and Kelbessa, E., 2010. Plant community distribution and variation along the Awash River corridor in the main Ethiopian rift. African journal of ecology, 48(1), 21-28.

Van den Berg, E.C. 2010. Detection, quantification and monitoring Prosopis spp. in the Northern Cape Province of South Africa using Remote Sensing and GIS. Doctoral Dissertation, Potchefstroom Campus of the North-West University, South Africa.

Wakie T.T, Evangelista P.H, Jarnevich C.S, Laituri M. 2014. Mapping Current and Potential Distribution of Non-Native Prosopis juliflora in the Afar Region of Ethiopia. PLoS ONE 9(11): e112854. doi: [10.1371/journal.pone.0112854]

WAS (Worer Agro meteorology Section). 2008. Annual Climatic record at Melka-Worer Agricultural Research Center. Annual Report. Worer, Afar, Ethiopia.

Witt, A.B., 2010. Biofuels and invasive species from an African perspective: a review. Gcb Bioenergy, 2(6), pp.321-329.

Yemane, B. 2007. Natural Resource and Environmental Management Considerations and Climate Healing Steps in Ethiopia. Paper presented at the Proceedings of the Fourth National Conference on Pastoral Development in Ethiopia: Millennium Development Goals and Pastoral Development: Opportunities & challenges in the new Ethiopian Millennium, Addis Ababa, Ethiopia.

Yibekal Abebe Tessema. 2012. Ecological and Economic Dimensions of the Paradoxical Invasive Species- Prosopis juliflora and Policy Challenges in Ethiopia. Journal of Economics and Sustainable Development. ISSN 2222-1700 Vol.3, No.8, 2012.

Zeila, A., 2011. Mapping and managing the spread of Prosopis juliflora in Garissa County, Kenya (Doctoral dissertation, Kenyatta University).

Tessema, Y.A 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): 62-70.

Rai, Prabhat Kumar. 2015. Environmental Skeptics and Critics: What makes the plant invasion possible? Paradigm of invasion mechanisms, theories and attributes. International Academy of Ecology and Environmental Sciences, ISSN 2224-4263. RSS: [http://www.iaees.org/publications/journals/environsc/rss.xml]