Climate change intensification impacts and challenges of invasive species and adaptation measures in Eastern Ethiopia

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ABSTRACT

Invasive alien species (IAS) are the plant species whose introduction and spread outside of their natural past, present and threatens biological diversity. Prosos: juliflora impacts and driver pastoral vulnerability and agricultural lands where reduced biodiversity, loss of livestock forage and culturally valuable of indigenous species. The major adverse impacts of climate variability in Ethiopia include food insecurity arising from droughts and floods, outbreak of diseases, land degradation due to heavy rainfall. Climate change adaptation and mitigation prevent the introduction of new non-native species to minimize the possibility of future invasions. As compared to the current climatic condition, future climate prediction in 2070 will be highly suitable climate for the species by increasing by 73.3% and 80.0% under RCP4.5 and RCP8.5 scenario, respectively. Further reviews that consider different climate models with appropriate adaptation management options are necessary to better understand the impact of future invasive species in the study area.

1. Introduction

Prosopis species is one of the highly invasive plants in the world. P. juliflora is in IUCN’s new list of 100 world’s worst invasive alien species (Mwangi & Shallow, 2005) and its invasiveness is also factual from economic point of view because they are in conflict with other human land use (Geesing et al., 2004). The impacts from invasive alien species (IAS) can be compounded by climate change the change in the Earth’s climate due to rising greenhouse gas emissions. Invasive species are species of all taxonomic groups whose introduction and/or spread outside their natural past or present distribution threaten the environment such that the well-being of humans will ultimately be affected (1). The species are characterized by rapid reproduction and growth, high dispersal ability, phenotypic plasticity (ability to adapt physiologically to nSw conditions), and ability to survive on various food types and in a wide range of environmental conditions.

In East Africa, P. juliflora was introduced in the 1970s through collaborative projects involving local governments and outside agencies (Coppock et al., 2005). In Ethiopia, it was first introduced in the Afar region in the 1970s by the Ministry of Agriculture from India in an effort to improve water and soil conservation and fight desertification (Ethiopian Agricultural Research Organization and Henry Double Day Research Association (EARO and HADRA), 2005). In many other countries in the tropics, hundreds of alien plant species have entered Ethiopia intentionally and unintentionally (Abdulahi et al., 2017). In the country, there are many invasive plant species that are posing negative impacts on native biodiversity, agricultural lands, range lands, national parks, water ways, lakes, rivers, power dams, road sides and urban green spaces with great economy and social consequences being reported (Reaser et al., 2007; Abdulahi et al., 2017). Invasive plant species reduces the effectiveness of development investments by choking irrigation canals, fouling industrial pipelines and threatening hydroelectric schemes thus, contributing to social instability and economic hardship, placing constraints on sustainable development, economic growth, poverty alleviation and food security (Habtam, 2015; Abdulahi et al., 2017). Previous works conducted in Southeastern Ethiopia indicated presence of the invasive plants for a long period of time (Takele, 2006 and Teshome, 2006). Invasions of invasive plants hinder crop production through claiming agricultural lands and serving as a hiding place for crop pests and wild animals.

Invasion by alien (exotic) tree species is the most common type of invasion and has attracted increasing attention because of the associated economic costs (Pimentel, 2001) and because they reduce native...
biodiversity or alter ecosystem functions (Catford et al., 2009). The alien species are considered the second great-
est agent of change to ecosystems after habitat change
Pejchar and Mooney (2009). The impacts on livelihoods
are most likely more pronounced in developing nations
because the majority of the populations in those coun-
tries consist of small-scale farmers who are dependent
on natural resources for their survival (Stefan, 2005).
Once an invasive species becomes firmly established,
control can often be difficult, and eradication is usually
impossible, if not merely too expensive (Cacho et al.,
2008). Prosopis species have invaded over 4 million
hectares in Africa (Witt, 2010). A recent estimate
shows that such invasions cost the world economy hun-
dreds of billions of dollars each year (CBD, 2010).

P. juliflora is among the IAS that has become a
wide spread problem in the country. P. juliflora
belongs to the family Fabaceae (Leguminosae), subfam-
ily Mimosoideae, and genus Prosopis (Asflaw & Thulin,
1989). It is native to North, South, and Central America
and the Caribbean (N. M. Pasiecznik et al., 2001). It is
a spiny, prickly, or armed shrub/tree that is fast growing
and has the ability to develop extensive, deep root sys-
tems, sometimes exceeding 20–25 m (Jorn, 2007).
Mature P.juliflora, under favorable growing conditions,
can develop into a tree with a height of 20 m and a
diameter of over 1 m (Jorn, 2007; N. M. Pasiecznik
et al., 2001). Ethiopia’s economy is highly exposed to
climate change and variability. Agriculture forms the
basis of the country’s economy contributing about
40% of the GDP and employing 85% of the population
(Byerlee et al., 2007). The rainfed nature of Ethiopia’s
agriculture implies that agricultural production is sensi-
tive to fluctuations in rainfall. P. juliflora was intro-
duced into high-quality pasturelands and irrigable areas,
including the Awash River basin in the Afar National
Regional State of East Ethiopia, during the 1970s as
a measure to control desertification and the high dust
wind in the area (Alemayehu, 2006). The tree is widely
considered to be a powerful invader and is becoming
a problematic weed in Ethiopia, especially in the Afar
State, invading large-scale farms, rangelands, and river-
banks (Shiferaw et al., 2004). Both the local government
and communities declared the invasion a top-priority
problem and requested external support to prevent
further expansion of the invasion and the restoration
of invaded areas (Farm-Africa, 2009).

The impact of invasive species is more critical in the
developing world where livelihood is primarily depen-
dent on agriculture (Chenje & Katerere, 2006).
Consequently, invasive species management is one of
the strategic intervention areas in achieving the
Millennium Development Goal1- to halve hunger and
poverty by 2015 (Chenje & Katerere, 2006). Apart from
their direct effect on livelihood, invasive species are one
of the five drivers of biodiversity loss together with
habitat loss, over exploitation, climate change, and pol-
lution (Millennium Ecosystem Assessment, 2005).

However, in most developing countries, there is gen-
erally insufficient information regarding the invasion
rate and impacts of P. juliflora, which arises from
a lack of resources for conducting research and data
collection (Witt, 2010). In Ethiopia’s Afar Region, with
90% of the Afar population being agro-pastoralists
and their livelihood mainly depending on livestock produc-
tion using rangeland, more than 700,000 ha has already
been invaded as Prosopis juliflora rapidly spreads across
both pastoral and agricultural lands (Mahn et al., 2010).
The ecological consequences have been devastating
since rangeland areas are degraded due to severe losses
in ecological functions and forage grass productivity has
declined drastically. Rangelands are areas which, by
reason of physical limitations, low and erratic precipita-
tion, rough topography, poor drainage, or extreme tem-
perature, are less suitable for cultivation but are sources
of food for free ranging wild and domestic animals, and
of water, wood, and mineral products.

These climate-related disasters, particularly drought,
have significant negative impacts on agriculture, rural
livelihoods, food security and economic development.
Furthermore, increasing livestock densities on the
remaining pasture land trigger continuing land degrada-
tion. Under these conditions, the vulnerability of pastor-
lists has increased and drought-induced acute food
insecurity has been replaced by chronic food insecurity
for large parts of the pastoral population. Prosopis julif-
flora high coppicing ability and the deep roots enable it to
survive in desert areas and provide a number of benefits
including alternative energy sources. The pods from
Prosopis juliflora can also be a source of nutritious
human food (Chogle et al., 2007), and can be a source of
nutritious, less costly feed ingredient for livestock (Sawal
et al., 2004; Stein et al., 2005; Chaturvedi & Sahoo, 2013).

Therefore, the overall objective of this review was to
assess the Climate change intensification Impacts and
Challenges of Invasive Species and Adaptation
Measures by using different scenarios in Eastern
Hararghe Zone, Ethiopia. Specifically, review was con-
ducted to achieve the following specific objectives. Review
gaps and opportunities in addressing the chal-
genesis of invasion species on the study area. Assess the
vulnerability and risks to agriculture production as
a result of climate change. Explore the threats faced by
the impacts of invasive species associated with
ecological and socioeconomic areas. Create the plan for integrating adaptation and mitigation climate change action to minimize alien species.

2. Impacts of climate change, challenges of invasive species and adaptation measures

2.1. Concepts and definition of key terms

Invasive alien species (IAS); are animals, plants or other organisms that are introduced into places outside their natural range, negatively impacting native biodiversity, ecosystem services or human well-being. Moreover it also refers to plants, animals or microorganisms that are not native to specific ecosystem and whose introduction threatens food security, biodiversity, health or economic development (McNeeley et al., 2001). Invasive species are of concern because of their capability of spreading fast, their high competitiveness and ability to colonize new areas within short periods. The nature and severity of the impacts of these species on society, economic life, health and national heritage are of global concern (McNeeley et al., 2001). In Afar a region, Prosopis juliflora is also attributed to have increased crop yields by 29% (Haji & Mohammed, 2013).

According to CBD (2005), invasive alien species are introduced deliberately or unintentionally outside their natural habitat, where they have the ability to establish themselves, invade, out-compete natives and take over the new environment. Moreover, they can reproduce sexually and asexually. Invasive species have significant social, ecological and economic impacts. They reduce agricultural yields, irrigated crop lands, grazing areas, water availabilities, and contribute to the spread of vector born diseases (Essa et al., 2006).

Weather is the current atmospheric condition in a given place. This includes variables such as temperature, rainfall, wind or humidity. Anyone looking outside can see if it is raining, windy, sunny or cloudy and can find out how hot it is by checking a thermometer or just feeling it. Weather is what is happening now, or is likely to happen tomorrow or in the very near future.

Climate change: Climate change refers to a significant and sustained (over decades or longer) change from one climatic condition to another. The change in climate attributed directly or indirectly to human activity, in addition to natural climate variability is observed over comparable time periods. It’s a significant shift in the mean state and event frequency of the atmosphere. The manifestation of climate change such as rising temperature, increasingly erratic rainfall, frequent and severe floods and droughts has serious consequences on the livelihood security of smallholder farming communities, making them more vulnerable and difficult in living life standard. Agriculture plays a great role in the livelihood of rural communities in many African countries (Gizachew. & Shimelis., 2014).

Climate variability:- Climate variability is defined as a variation in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events. It is often used to denote deviations of climatic statistics over a given period of time (month, season or year) when compared to long-term statistics for the same calendar period. El-Nino of Southern Oscillation (ENSO) is an example of climate variability through ocean–atmosphere interactions. There is a significant relationship between climate and agricultural production in terms of timing, variability, quantity of seasonal and annual rainfall and temperature in Ethiopia. According to (Mintewab et al., 2010) higher temperatures and changing rainfall level as a result of the climate change will further depress agricultural production in many arid and semi-arid parts of Ethiopia over the coming decades.

Vulnerability is a multidimensional concept which varies across temporal and spatial scales and depends on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors. It is the degree to which a system will respond to a given change in climate including beneficial and harmful effects.

2.2. The Major types of invasive alien species

2.2.1. Parthenium hysterophorus L

Parthenium hysterophorus, known as Parthenium weed, has in recent decades become one of the fastest spreading and most menacingly destructive of all alien plant invaders. Native to Mexico, Parthenium weed has long been a scourge on the Indian sub-continent and in Australia, having in both regions been introduced accidentally in the 1950s as a seed-contaminant in imported produce. The local name of thesis species is Faramsiisa (Oromia); Harama dhambil (Somalia).

In Ethiopia, it is believed to have been introduced in 1976/77 with army vehicles from Somalia and has become a serious weed both in arable and grazing lands (Tamado et al., 2002). Others also believed that P. hysterophorus may have also been spread through the provision of humanitarian emergency food aid. For example, this weed was an introduction to Africa through grain shipments for famine relief to Ethiopia (McNeeley et al., 2001). The weed was first seen in 1980s near food-aid distribution centers in Ethiopia (GISP, 2004). However, currently, it is widely distributed in Ethiopia. In eastern Ethiopia, Tamado (2001) reported that parthenium weed is the second most frequent weed (54%) after Digitaria abyssinica (63%). The presence of
Parthenium in Kenya and Somalia (Njorage, 1991) and the capacity of the seed to travel long distance through wind, water, and other means also suggested the possible entry into Ethiopia from these neighboring countries.

In the Amhara region, it is estimated that about 37,105 hectares of land is infested with parthenium (Bezabieh & Araya, 2002). It is abundantly found in Gojjam, in south and north Gonder with the potential to spread to agricultural districts of Metema and Setit Humera (Bezabieh & Araya, 2002). Furthermore, the weed is well established in many districts of South, north, and central Tigray. In one district alone, Alamata, about 10,000 hectares of the land has been infested with parthenium (Bezabieh & Araya, 2002). In much of the low lands of Wello, Parthenium has become the most dominant weed. The weed is also a serious problem in the Regional State of Oromia although there are no actual survey data on the total area of land infested in the region. Currently, Parthenium is spreading at an alarming rate in Eastern Ethiopia; the central rift valley, and neighboring localities of Afar Region, East Shewa, and Bale and in Southern Ethiopia (Taye, 2002) reported that the plant occurred in the towns, usually on roadsides, and vacant sites and grew only at irregular intervals.

**Agricultural, human and other impacts**

Reducing agricultural and pasture productivity: Parthenium exerts strong allelopathic effect and reduces the growth and reproductiveness of associated crops. It does these by releasing phytotoxins from its decomposing biomass and root exudates in soil. Bioassay, pot culture and field studies have revealed that all plant parts (shoot, root, inflorescence and seed) are toxic to plants (Jarvis, 1985). Parthenium roots of decayed plant release soluble sesquiterpene lactones, mainly partenin (Pandey & Dubey, 1993). These chemicals inhibit the germination and growth of plants including pasture grasses, cereals, vegetables, and other plant species (Evans, 1997a).

**Health hazards to humans and livestock:** Persons exposed to this plant for prolonged period manifest the symptoms of skin inflammation, eczema, asthma, allergic rhinitis, hay fever, black spots, burning and blisters around eyes. *Parthenium hysterophorus* also causes diarrhea, severe popular erythematous eruptions, breathlessness and choking (Maishi et al., 1998). Exposure to *P. hysterophorus* also causes systemic toxicity in livestock (Gunaseelan, 1987). Alopecia, loss of skin pigmentation, dermatitis and diarrhea has been reported in animals feeding on *P. hysterophorus*. The milk and meat quality of cattle and sheep deteriorate on the consumption of this weed (Lakshmi & Srinivas, 2007).

**Biodiversity loss:** Parthenium is an aggressive weed and therefore poses a serious threat to the environment and biodiversity owing to its high invasion and allelopathic effect which has the capacity to rapidly replace the native vegetation (Pandey & Dubey, 1993). It has been reported to be causing a total habitat change in native Australian grasslands, open woodlands, river banks and flood plains (Lakshmi & Srinivas, 2007).

### 2.2.2. *Eichhornia crassipes* (mart.) solms

*Eichhornia crassipes*, commonly known as water hyacinth; common water-hyacinth; free-floating water hyacinth is a perennial aquatic plant (hyrophyte) native to the Amazon basin (to tropical and sub-tropical South America), and is often considered a highly problematic invasive species outside its native range. With broad, water hyacinth may rise above the surface of the water as much as 1 meter in height. In their native range, the flowers are pollinated by long-tongued bees and they can reproduce both sexually and clonally (Toft et al., 2003).

Water hyacinth was the most abundant aquatic weed on the water bodies and perceived as one of the most important noxious weeds (Midgley et al., 2006). Water hyacinth has become a major invasive alien weed in the water regions of the country having successfully established and invaded the different water bodies. In all water bodies, there was a high degree of variability in water hyacinth infestation. Water hyacinth is problematic at Koka Dam along the Awash River, and in Gambela along Baro, Gilo, Pibor and Sobate rivers. These lakes are located near the farm lands and even part of them is cultivated when the water level decreases.

**Socio-economic and environmental impact**:- As reported by different scholars, impact of water hyacinth gets higher whenever there were mats (Center et al., 2002). The most noticeable impacts that were reported by most researchers include restricting proper water flow, water loss through excessive evapotranspiration, interference with fishing, grazing and crop production activities (accessibility to land water hindered), effect on power generation, increase siltation, flooding, increase the cost of production and effect on native plants (Midgley et al., 2006). Though vital epidemiological data pertaining to the incidence of human diseases were not obtained during this review, there is a general increase in disease incidences as a result of provision of vector breeding grounds. Some of the human diseases reported include skin rash, malaria, and bilharzias (Ding Julien et al., 2001). These results showed that the impact of water hyacinth may be categorized into social, economical and environmental impacts. The negative impacts of water hyacinth are due to its dense,
impenetrable mats which restrict access to water. These mats affect fisheries and related commercial activities, functioning of irrigation canals, navigation/transport, hydroelectric programmes and tourism (Navarro & Phiri, 2000).

2.2.3. Prosopis juliflora (Sw.) DC

Prosopis juliflora is a shrub or small tree in family fabaceae, a kind of mesquite. It is native to Mexico and the Caribbean. The Local name is Prosopis (name being adopted in Ethiopian Languages). Tree or shrub, armed with stipular spines and has stem with a diameter of up to 1.2 m. It is the most aggressive weed that cause great devastation to subtropical grasslands and was thought to have been introduced to Ethiopia during the establishment of irrigation water development project at Middle Awash as wind break, shade and shelter (Abiyot and Getachew, 2006). This species is now commonly found in Afar National Regional State (ANRS) and spreading to Oromia, Amhara, Somali, and Dire Dawa regions. Nowadays it is repeatedly reported to be one of the invasive and problematic trees in the Afar region as well as in the country.

Many scholars reported that the species has been increasing in density as well as area coverage from year to year even from month to month (El-Keblawy et al., 2005). Currently, this noxious tree heavily infests most agricultural as well as potential range lands in the Afar region (Hailu et al., 2004). The thorny nature of the plant, remarkable ability to withstand adverse conditions, non-browse able nature, and above all, the nomadic nature of the people have paved the way to invade most potential lands of the region. El-Keblawy (2002) indicated that P. juliflora shows a great depressive effect on the number, density, and frequency of native vegetation. Currently, Prosopis invasion is estimated well above 1million hectares (1,117,510 hectares) taking over prime grazing and irrigable land in Afar region alone and the spread of the plant is advancing at the rate of about 50,000 hectares annually (Hailu et al., 2004).

2.3.3.1. Dispersal mechanism prosopis juliflora.

Dissemination mechanisms of seeds by domestic and wild animals and the ability to germinate immediately after dispersal give P. juliflora great opportunity to grow faster and makes it a more adapted species to drought condition (Hailu et al., 2004). The number of P. juliflora seeds in the soil seed bank is greater than the seeds of native tree species (Al-Rawahy et al., 2003). The plant accumulates long lived dormant but viable seeds in the soil serving as a source of new P.juliflora plants in the event of disturbance that might eliminate the above ground stands (Hailu et al., 2004). According to Hailu et al. (2004), under optimal condition only a portion of the seeds (21%) germinate at any one time, suggesting that the seeds have high dormancy caused by the hard seed coat. This is particularly important for species survival in arid environments regardless of spatial and temporal rainfall distribution (El-Keblawy and Al-Rawai, 2006).

P. juliflora has two main ecological opportunity behaviors: seed dormancy (Hailu et al., 2004) and allelopathic effects (Moa & Al-Humaid, 1998). They also reported that P. juliflora plants possess allelochemicals that inhibit germination, growth and survival of other species. El-Keblawy and Al-Rawai (2006) also explained that the density of P. juliflora seedlings is greater underneath the canopy of the same species than away from them. This indicates that the plant has little or no auto-inhibition effect under field conditions. Removal of P. juliflora enhances diversity of other species with its ameliorating effect of some soil characteristics through increasing in K, N and P and organic matter (El-Keblawy and Al-Rawai, 2006). P. juliflora has many biological characteristics that promote for its invasion of new area. The plant produce mixture of seeds, few of them germinate immediately after dispersal and the majorities remain dormant for future germination; the pods are flesh and sweet that attract domestic and wild animals.

3.3.3.2. Current and future predicted P. juliflora distributions. The predicted model showed that 94.8% of the country is non suitable for P. juliflora under the current climatic conditions while 0.4% is highly suitable (Table 1). We find that additional 3.2% and 1.6% of Ethiopia has a low and moderate suitability for P. juliflora, respectively.

P. juliflora has a geographically narrow distribution in the country under the current climatic condition covering significant parts of Afar Region and adjacent Amhara, Oromia and Tigray Regions. Its distribution is especially widespread within the north eastern part of the country but also extends to east including Dire Dawa city Administration and Somali Region (Figure 1).

| Decades | Current Scenarios | Total suitability (%) |
|---------|------------------|----------------------|
|         |                  | Not suitable | Low | Moderate | High |
| 2050    | RCP4.5           | 92.6         | 4.1 | 2.4     | 0.9  |
|         | RCP8.5           | 90.9         | 5.2 | 2.8     | 1.1  |
| 2070    | RCP4.5           | 89.6         | 5.6 | 3.3     | 1.5  |
|         | RCP8.5           | 88.6         | 5.7 | 3.7     | 2    |

(Source: Sintayehu et al., 2020)
As compared to the current distribution, by 2050, the total area of highly suitable area for P. juliflora under RCP4.5 and RCP8.5 will gradually increase to 0.9% and 1.1%, respectively. The total area of the unsuitability for P. juliflora will decrease by 2.4% and 4.3% under RCP4.5 and RCP8.5, respectively, whereas high suitability for the species will increase by 55.6% and 63.6%, respectively (Table 2). Under similar scenario RCP4.5 and RCP8.5 in 2050s, the total moderate suitable area is projected to increase to 33.3% and 49.9% under RCP4.5 and RCP8.5 scenario, respectively. Overall, areas considered with low suitability in the country will increase to 21.9% and 35.5% under RCP4.5 and RCP8.5 scenarios. Compared to the current climatic condition, in 2070, highly suitable climate for the species is projected to increase by 73.3% and 80.0% under RCP4.5 and RCP8.5 scenario, respectively. Moreover, moderately suitable area will increase by 51.5% and 56.8% under RCP4.5 and RCP8.5 climate scenario in 2070, respectively. In the same period, the total non suitable area for P. juliflora under RCP4.5 and RCP8.5 scenario is expected to decrease by 5.8% and 7.0%, respectively (Table 2).

3.3.3.4. Distribution and abundance of Prosopis juliflora. Generally, it was more or less evenly distributed over many sites (Figure 2). The plant had been frequently abundant (30–50%) on about 13 interceptions. It had very abundant (75–100%) and abundant (50–75%) infestation levels respectively at Amibara and Dubti districts (Figure 2). The altitude within which Prosopis was recorded ranged from 347 m to 1005 m a.s.l. with the mean altitude of 620 m a.s.l. (Figure 2).

About 32.69% of the sample waypoints in which Prosopis occurred were on roadsides followed by habitation areas (26.92%). The least occurrence of the species was found in forests (7.69%) (Figure 3). This result indicated the domination and colonization of Prosopis along roadsides. Similarly, Shashitu (2008) also observed that Prosopis invasion was high around roadsides than other habitats since Prosopis seeds were distributed from one place to another by animals through their dung along roadsides. Prosopis infestation around habitation areas ranged from abundant (75–100%) to frequent (30–50%) levels (Figure 4). Generally, the plant showed its ability to invade diversified habitats in the surveyed areas. The adaptability of Prosopis in different habitats is mainly attributed to the ability of the plant to produce many, small and hard seeds that can survive

Table 2. Percentage of change (gain or loss) of suitability for P. juliflora under current and future (2050 and 2070) climate change in Ethiopia under RCP4.5 and RCP8.5 climate change scenario

| Decades | Current | RCP4.5 | RCP8.5 | Total suitability (%) |
|---------|---------|--------|--------|-----------------------|
| 2050    | -       | -2.4   | 4.3    | 32.2                  |
|         |         | 21.9   | 38.5   | 53.3                  |
|         |         | 33.3   | 42.9   | 63.6                  |
| 2070    |         | -5.8   | -7.0   | 42.9                  |
|         |         | 51.5   | 36.8   | 73.3                  |
|         |         | 56.8   | 80.0   |                       |

(Source: Sintayehu et al., 2020)
after passing through the digestive system of animals, attractive and rewarding pods for animals, accumulation of long-lived seeds in the soil, ability of seedling survival under stressed conditions, ability of regeneration and fast coppice growth from stumped/damaged trees (Ameha, 2006; Hailu, 2002).

2.4. Impacts of Prosopis juliflora invasion

_P. juliflora_ possess allelochemicals that inhibit the germination and spread of other plant species (Essa et al., 2006). The number of annual plants significantly reduced under the canopy of _P. juliflora_ (Essa et al., 2006). The plant has little or no self allelopathic (auto-inhibition) effect under field condition (El-Keblawy and Al-Rawai, 2006). This mechanism, combined with drought condition can inhibit other species and eliminate any kind of competition. The invasion is threatening livelihood of pastoralists and agro-pastoralists due to loss of pasture and destruction of croplands. Dense thicket that is impossible for people or cattle to penetrate. Vine-like runners provide fine ground cover and protect land, but at the expense of productivity– native vegetation is smothered and traditional crops can no longer be grown. It affects the flood plains along the river Awash. Mechanical injuries to livestock and people and intestinal obstruction and jaw problems on livestock (Table 3) were impacts of _P. juliflora_ in the area (Essa et al., 2006).

2.4.1. Impact of Utilization versus controlling _P. juliflora_

Various attempts had been made to eradicate and control _P. juliflora_ in the study area but proven unsuccessful and ineffective. Hence, changing the view and aiming on harvesting and utilization of the deliberate introduction of _P. juliflora_ as a valuable resource to support rural livelihoods in the dry lands is become possible controlling strategy to minimize the spread of _P. juliflora_. Respondents requested about their opinion on the current correlation between utilization rate and invasion rate. Accordingly, all exploiter groups agreed that the
The current invasive rate was greater than exploitation rate at different extent (Table 4).

The following evaluation criteria shows the current exploitation rate of *P. juliflora* verses their relative invasion rate on 12 judgment criteria; 5 = invasion rate is extremely higher than exploitation rate, 4 = invasion rate is very higher than exploitation rate, 3 = invasion rate is higher than exploitation rate, 2 = invasion rate is fairly higher than exploitation rate, 1 = invasion rate is slightly higher than exploitation rate, 0 = invasion rate is comparable to exploitation rate −5 = invasion rate is extremely lower than exploitation rate, −4 = invasion rate is very lower than exploitation rate, −3 = invasion rate is lower than exploitation rate, −2 = invasion rate is fairly lower than exploitation rate, −1 = invasion rate is slightly lower than exploitation rate.

### 2.4.2. Causes and Impacts of *Prospis juliflora* of Invasive Alien Species

Globalization has resulted in greater trade, transport, travel and tourism, all of which can facilitate the introduction and spread of species that are not native to an area. If a new habitat is similar enough to a species’ native habitat, it may survive and reproduce. For a species to become invasive, it must successfully out-compete native organisms for food and habitat, spread through its new environment, increase its population and harm ecosystems in its introduced range. IAS are one of the biggest causes of biodiversity loss and species extinctions and are also a global threat to food security and livelihoods. It is essential that IAS be incorporated into climate change policies. This includes biosecurity measures to prevent the introduction of IAS to new regions as a result of climate change, and rapid response measures to monitor and eradicate alien species that may become invasive due to climate change. It is a multipurpose tree/shrub that is used for feed of livestock, shade, windbreak, charcoal, live fence, and firewood as well as house construction (Hailu et al., 2004; N.M. Pasiecznik et al., 2003).
According to the World Conservation Union, invasive alien species are the second most significant threat to biodiversity, after habitat loss. In their new ecosystems, invasive alien species become predators, competitors, parasites, hybridizers, and diseases of our native and domesticated plants and animals. Most countries such as Sudan, Ethiopia, India, Kenya and Tanzania affected by *P. juliflora* have major troubles in irrigation canals during the dry period (Mwangi & Shallow, 2005). The impacts of invasive species include reduced biodiversity. Decreased availability and quality of key natural resources. Water shortages. Increased frequency of wildfires and flooding. Pollution caused by overuse of chemicals to control infestations.

2.5. The Drivers of Vulnerability and Effects of Invasive Alien Species on the Pastoralist Livelihoods

2.5.1. Invasive species *P. juliflora* and pastoralists in eastern Ethiopia.

IAS is species that have not only become naturalized but thrive in their non-native environment, reproducing viable offspring and spreading a considerable distance from the introduction site (Pyšek Petr et al., 2004; Richardson et al., 2000). A very aggressive invader, *P. juliflora* is a “conflict species”, conferring benefits (Pasiecznik & Smith, 2004) as well as costs, and has been present in Africa for over 100 years (CABI, 2011). It was actively introduced in the 1970s and 1980s by governments and development professionals in East Africa to provide fuel wood and regenerate arid regions (Muanda et al., 2009; Muturi, 2012; Odour & Joseph, 2013), although in Ethiopia there is a lack of clear documentation relating to its exact introduction pathway (Mehari and Zeraye, H, 2015). The extensive invasion in the study area in eastern Ethiopia now affects a considerable, and growing, portion of Afar (Haregewyn et al., 2013; Surafel Lulseged & Asfaw, 2012; Wakie et al., 2014) (Figure 5). Whilst studies exist on a local level stressing the environmental and economic impacts (Muanda et al., 2009), articulation and exploration of the social impacts are generally absent.

The Afar experience many of the challenges common to other pastoralist groups, suffering development interventions that are often culturally insensitive (Tadesse & Adaye, 2007) and at times willfully deleterious to local norms and practices (Redie, 2014). Common pasture-land in eastern Ethiopia is already under pressure, frequently appropriated by external cotton and sugarcane plantations (Roy & Kerven, 2013), with the allegation that a formal judiciary offers limited recourse for resolving grievances (Abebe & Bekure, 2013). The approach to pastoralism by successive Ethiopian governments has been to coerce or force people out of pastoralism into purportedly modern and efficient activities through the pursuit of large-scale commercial agriculture, the establishment of national parks and sedentarisation (Gebeye and Berihun Adugna, 2016). Gebeye (2016) claims that none of these approaches were successful or appropriate for pastoral priorities and needs. Notwithstanding the 2011 Afar National Regional State Proclamation, articulating institutional responsibilities (Chekol, 2014) and establishing regulations intended to control, manage and eradicate *P. juliflora* in the region (Said, 2015), such a policy environment frustrates the formulation of an appropriate response to the pastoral impacts of invasive species (Figure 5).

2.5.2. Drivers of pastoral vulnerability.

The pastoral context in eastern Ethiopia and the characteristics which render pastoralists vulnerable to environmental change are the subject of significant study,

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*Figure 5. Map of study area.*
with the concept of vulnerability used to describe “states of susceptibility to harm, powerlessness, and marginality of both physical and social systems” (Adger, 2006). There is evidence of their sensitivity to global economic shifts, including food price spikes (Makki, 2012), and to changes in the domestic political economy and specifically the state’s interventions in driving enclosure (Lavers, 2012). Sedentarisation can be seen as both a driver of vulnerability and a solution to vulnerability for pastoralists (Galvin, 2009). In terms of increasing vulnerability, when sedentarisation has been led by the state or forced upon pastoralists through land grabbing or drought, this has reduced land rights, eroded customary institutions and harmed livelihoods (López-i-Gelats et al., 2016). As sedentarisation erodes pastoral institutions, communities become increasingly exposed to conflict (Barrow et al., 2007). However, sedentarisation can also be adopted as an adaptation strategy in the face of climate change or incidence of livestock disease, or adopted in response to incentives (Galvin, 2009).

The capacity of pastoral communities to adapt to changing ecological conditions is compromised by their diminished economic and political standing and hence marginalisation. The external imposition of change and adaptations (Tsegaye et al., 2013) drives pre-existing tension and distrust between the government and local communities and political marginalization. This contributes to a diminished indigenous capacity to manage risk, and the poor accounting of social capital leads to misrepresentations of the types of risk communities face (Davies and Bennett, 2007).

2.5.3. Pastoralism and *prosofid juliflora.*

*P. juliflora* and the variety of impacts associated with its invasion present another driver of pastoral vulnerability. Costs include changing local environments, where reduced biodiversity translates into the loss of culturally valuable indigenous species in Kenya (Stave et al., 2007), and in southern Afar is linked to the loss of livestock forage and fodder (Mehari and Zeraye, H., 2015). Drawing on participatory research (Wakie et al., 2016) also highlight the perceived loss of native species in southern Afar, in addition to increased livestock morbidity and mortality and a loss of indigenous culture.

However, *P. juliflora* is perceived as both a negative and positive introduction, and perceptions, and priorities, vary between elite agents and local communities, as the court case launched by pastoralists against the Kenyan government over the invasion of their grazing lands demonstrates. The relationship is complex and at times contradictory; analysis of the impacts of *P. Juliflora* in eastern Ethiopia by (Negussie et al., 2017) found the invasion increased income from crop production and off-farm activities whilst reducing income from dairy production, and in South Africa (Shackleton et al., 2015) conclude that land users accessing common property resources recognize the perceived costs but are less focused on management than private landowners. Pastoral environmental stewardship is not just a strength but a necessity, supporting ecosystems which demonstrate more biodiversity in grazed areas (Maitima et al., 2009), managing livestock systems which offer greater productivity over ranching and only posing a threat to wildlife through competition when resources are forcibly shared, with no clear evidence that pastoralism leads to “competitive exclusion” (Bilal & Matthew, 2012).

2.6. Impacts of climate change and IAS on agriculture

Agricultural weeds, insect pests and crop diseases are all sensitive to temperature and precipitation and some are responsive to atmospheric CO₂ concentrations. Understanding how climate change will affect IAS pest, pathogen and weed species is important to enable accurate impact assessments of climate change on agriculture. Usually, this understanding comes from scenario modelling and expert opinion. As climate changes, patterns of production and trade in agricultural commodities will change as well with crops adapted to tropical conditions being grown more competitively in higher latitudes and altitudes (Masters et al., 2010). The opportunities for tropical IAS to contaminate such crops in new ranges will also increase. It is expected that climate change would decrease pesticide efficacy, which would necessitate changes to disease forecasting models and disease management strategies. This could involve heavier and more frequent applications, with potential threats to non-target organisms and increased water pollution, as well as increased costs associated with pesticide use. Similar trends are predicted for herbicides in the future. Climate change is expected to impact on the agricultural sector in multiple ways, among others through increased variability with regard to temperature, rain, frequency and intensity of extreme weather events, changes in rain patterns and in water availability and through perturbations in ecosystems.

Climate change will have a range of impacts on agricultural systems and production. It is likely that the life cycle of crops will progress (advanced phenology) more rapidly; but with rising temperatures and variable rainfall, crops will begin to experience failure, especially if there is a decrease or increased variability
in precipitation. Gains and losses are predicted for crop yields, for example, depending on locality, crop type, production system and, importantly, climate change model adopted. Increased moisture stress and drought are major concerns for both irrigated and non-irrigated crops. If adequate water is not available, production declines and entire harvests can be lost. While climate change is expected to cause moisture patterns to shift, there is still considerable uncertainty concerning the magnitude and direction of such changes. Furthermore, longer growing seasons and higher temperatures would be expected to increase demand for water, as would changes in the frequency of drought. Water stress, increased temperature and the impact of an increased incidence and abundance of old and new invasive pests, diseases and weeds are almost certainly a major factor in the projected agricultural declines in the tropics. Invasive insect, disease and weed pests are likely to benefit most from climate change, leading to increased pesticide and herbicide use or greater reductions in yield. Warming accelerates plant development and reduces grain-fill, reduces nutrient-use efficiency, increases crop water consumption, and favors weeds over crops. Also, the rate of development of insects may be increased (Karuppaiah & Sujayanad, 2012).

2.6.1. Climate change susceptibility to invasive species

Invasive alien species (IAS) are species whose introduction and/or spread outside their natural habitats threaten biological diversity (SSCBD, 2009). Majority of the crop plants and animals in most parts of the world are introduced and hence, alien to the respective regions. The global impact of IAS has been recognized by the Convention on Biological Diversity (CBD), which calls for the control and monitoring of alien species that threaten ecosystems, habitats and species. Climate change is altering vital aspects of the environment such as temperature and precipitation, the frequency of extreme weather events, as well as the atmospheric composition and land cover. The temperature, atmospheric concentration of carbon dioxide (CO₂) and available nutrients are the key factors that will drive species survival; changes in these factors will most likely stress the ecosystems and the chances of invasions. Many scientists agree that climate change will alter destination habitat and increase vulnerability to invasion because of resource scarcity and increased competition among native fauna and flora.

Climate change and IAS present two of the greatest threats to biodiversity and the provision of valuable ecosystem services. Apart from the human-induced habitat destruction, IAS are the second most significant factor that controls environmental change worldwide, resulting in negative impacts on environmental conservation, economic growth, and sustainable development. Climate change impacts, including warming temperatures and changes in CO₂ concentrations, are likely to increase opportunities for IAS because of their adaptability to disturbance and to a broader range of bio-geographic conditions. The impacts of those invasive species may be more severe as they increase both in numbers and extent, and as they compete for diminishing resources such as freshwater. Warmer air and water temperatures may also facilitate the movement of species along previously inaccessible pathways of spread, both natural and human-made. Biological invasions are a widespread and significant component of human-caused global environmental change. Biotic invaders interact synergistically with other components of global change, such as land use change, increase in nitrogen deposition, in higher CO₂ levels and warmer temperatures, and increase in the frequency of extreme events such as storms and fire. The temperature, atmospheric concentration of carbon dioxide (CO₂) and available nutrients are the key factors that will drive species survival; changes in these factors will most likely stress the ecosystems and the chances of invasions (Simberloff, 2000).

2.6.2. The response and adaptation measures on climate change on alien species

As the impacts of IAS are increasingly compounded by a changing climate, policy responses addressing these issues need to take into account the links between the two issues. Climate change policies can incorporate IAS, by including IAS prevention and control, and by ensuring that measures to address climate change do not increase the threat of IAS. For example, native tree species should be used for carbon sequestration or erosion control rather than introduced species such as Acacia or Eucalyptus occurring outside their native range. Climate change should also be explicitly incorporated into risk assessments of IAS, to help identify those alien species that could become a threat in the future. Such stressed ecosystems may have more available resources that could facilitate the successful invasion of non-native plants (Taush, 2008).

Ecosystems need to be prioritised according to their vulnerability to climate change and IAS, making it possible to establish measures that will prevent IAS introduction. This should include establishing effective biosecurity measures to manage priority pathways of introduction, supported by early warning and rapid eradication to tackle alien species before they become
invasive. The increase and geographic redistribution of IAS will have diverse societal and environmental impacts. Biological invasions are a major threat to global food security and livelihoods, with developing countries being the most susceptible. These countries, which have high levels of subsistence and smallholder farming, often lack the capacity to prevent and manage biological invasions. IAS reduce the resilience of natural habitats, making them more vulnerable to the impacts of climate change. For example, some grasses and trees that have become IAS can significantly alter fire regimes, especially in areas that are becoming warmer and drier. This increases the frequency and severity of wildfires and puts habitats, urban areas and human life at risk. Therefore, IAS can also impact agricultural systems, by reducing crop and animal health. Invasive plant species can be both the result of global changes and the drivers of change. They may be harmful to crops, industries, the environment and public health (Vitousek et al., 1997).

2.6.3. Climate change and invasive alien species affect biodiversity
Climate change, through rising average temperatures, increased variability of rainfall (frequency; intensity), increased atmospheric greenhouse gas concentrations, increased frequency and severity of storms and rising sea level, will affect the invading species, its invasive potential and the invasibility of the host ecosystem, be it native or derived. The greatest impacts of climate change on invasive species may arise from changes in the frequency and intensity of extreme climatic events that disturb ecosystems, making them vulnerable to invasions, thus providing exceptional opportunities for dispersal and growth of invasive species. In many Mediterranean ecosystems, declining rainfall, more severe droughts, and more hot days increase wild fire risk. Certain IAS will benefit from these changes and reinforce them. Changing fire regimes has the strong potential to alter radically ecosystems, leading to switches in vegetation dominance and structure with substantial implications for management strategies and biodiversity. Invasive species management aims to prevent introductions, eradicate or contain populations, or mitigate their negative environmental, economic and social impacts (Simberloff et al., 2013).

By definition, IAS must arrive, survive and thrive in their new environment. Climate change will act on all three components of this invasive pathway. Climate and landscape features (including land use and land cover) set the boundaries for the geographical distribution of species and determine the seasonal conditions for growth and survival. Many invasive alien pathogens will also benefit from climate change as rising average temperatures (including warmer soil temperatures) and shorter and milder winters will promote pathogen growth and reproduction, and potentially higher transmission rates. As invasive species and climate change are considered two of the main threats to biodiversity, the two operating together could be expected to produce extreme outcomes. Synergistic combinations are likely to lead to significantly increased vulnerability with climate change. Elevated CO₂, increased temperature, changed precipitation patterns and an increased frequency of extreme events such as fire and flooding will all have significant impacts on ecosystems and IAS. The majority of prosopis species are considered in terms of providing erosion control, shade, fuel wood, building materials, animal and human consumption in arid and semi-arid regions, yet also having a negative impact on biodiversity, crop and pasture production, and water resources (N. M. Pasiecznik et al., 2001). Generally, IAS, such as weeds, pests and diseases, are extremely adaptable to climatic variability as shown by their current large latitudinal ranges. IAS also tend to have rapid dispersal characteristics, which allow them to shift ranges quickly in response to changing climatic conditions. As a result, these species could become more dominant in many areas under changing climate conditions.

2.6.4. Adaptation measures of invasive species in rangeland area
The management of invasive species is extending in scale and complexity in response to the growing impacts of introduced species (Hulme, 2006) and as technical advances enable increasingly ambitious projects that tackle multiple species and use more sophisticated methods (Campbell et al., 2015; Glen et al., 2013). Many such initiatives successfully achieve their targets (Simberloff, 2008 and Simberloff et al., 2013), but as ambitions grow, attempts to eradicate or control invasive species continue to generate controversy and conflict (Estevez et al., 2015). Even on uninhabited islands, the “social dimensions” of invasive species management (ISM) can significantly affect outcomes. Social impacts can arise from any issue associated with a policy, plan or project that directly or indirectly affects humans and human communities (Vanclay et al., 2015). International guidance for invasive species management states that interventions should be socially, culturally and ethically acceptable. (International Union for the Conservation of Nature, 2000) and practitioners, many of whom are ecologically trained, are now commonly encouraged to attend to “social”, or “human” dimensions of biological invasions (White et al., 2008). Whilst
this attention is often with a view to preventing or circumventing opposition to management (Blackburn et al., 2010; Estevez et al., 2015), there are important reasons for assessing social impacts that go beyond their potential to complicate project logistics.

2.7. Ecological and socioeconomic impacts of invasive species management strategies

Environmental consequences translate into socioeconomic impacts when they influence the ability of ecosystems to provide goods and services for humanity. Some species have direct effects across a variety of ecological features and socioeconomic sectors. There are three main methods used for control of invasive species biological, mechanical, and chemical. Biological control is the intentional manipulation of natural enemies by humans for the purpose of controlling pests. Mechanical control includes mowing, hoeing, cultivation, and hand pulling. Chemical control is the use of herbicides. Interventions include legislation, trade regulation, border controls, eradication, population controls, and restoration. Such impacts are rarely evenly distributed and can result in inequity where certain groups are disproportionately affected by action (Marshall et al., 2011). The governance and processes of management can themselves create social impacts. Excluding stakeholders from meaningful participation in deliberation and decision-making can produce distrust and animosity, as well as anxiety if people feel they lack control over decisions that affect them (Kahn et al., 1990; Zalom et al., 2013).

Established approaches; concerns about invasive species management are often attributed to deficits in understanding or insufficient awareness of “the problem”. The response to this apparent knowledge deficit has often been attempts to better inform or educate stakeholders. However, this strategic “public education” or “information deficit” model has been repeatedly criticized as ineffective, and for disempowering lay publics (Callon, 1999; Owens, 2000).

Furthermore, management activities targeting established species or recent introductions, which are often the focus of social disputes, infrequently require specific behaviors or behavioral change on the part of affected communities: rather, they require communities to engage with, support, or at least accept, management interventions (often delivered by others). Structured decision-making (SDM) sits between technocratic (analytic) and fully deliberative decision-making and is therefore referred to as an analytic-deliberative approach (Burgess et al., 2007). SDM assumes that a decision needs to be made and that a single body, or a group of open-minded decision-makers, is willing to critically assess a range of alternatives (Runge et al., 2013).

The analytic side involves the collection and processing of technical and ecological data, which is then fed into iterative, participatory processes. SDM could have extensive application for invasive species management (Estevez et al., 2015), but is not without challenges. First, analytic-deliberative tools normally require an understanding and prediction of potential social, environmental, and economic impacts of management alternatives before they can be evaluated and compared. Second, some social impacts arise in response to procedural issues (rather than as consequences of an intervention). SDM can therefore run the risk of creating unintentional social impacts through its implementation, especially where there are histories of distrust or tension amongst stakeholders and authorities.

2.7.1. Social impact assessment

Social impact assessment (SIA) was developed alongside Environmental Impact Assessment (Vanclay, 2012). Whilst both assess the potential impacts of development projects and are used to inform planners, they differ in philosophy and procedure. SIA focuses on human and community impacts of interventions rather than “environmental” impacts, although close interconnections between humans and their environments mean that social and environmental impacts can rarely be clearly differentiated.

A key advantage of SIA is its flexible structure. SIA promotes a deliberative approach to management, recommending community engagement from the start. As such, it has features in common with SDM, and we suggest that SIA could be integrated with relative ease into governance structures based on an SDM model. Indeed, SIA could facilitate effective SDM: contemporary SIA is highly reflective, and scoping procedures include consideration of how management planning processes, and the SIA itself, might affect and be received by concerned publics. In principle, there are three ways of controlling the damage of invasive species; prevention, control and adaptation measures. Prevention efforts inhibit the entrance of species into new regions, control measures regulate the size and spread of the invader, and adaptation measures affect the damage caused by the invader through adjustments of economic activities at the site such as, e.g. the management of native species already present in the habitat (Finnoff et al., 2005 for definitions of the different types of measures). The next, present an adapted framework for SIA of invasive species management, in five stages: scoping, assessment, decision-making, implementation and appraisal (Figure 6).
2.7.2. Utilization fire and prevention framework

One of the possible options to manage invasion species is through utilization fire. They can be utilized for the production of biogas, compost especially vermicompost (Yadav & Argaw, 2016) and as a green manure. Plants up to pre-bloom stage should only be used otherwise while handling such material, dispersal may take place. Regular burning will reduce the capacity of invasive alien species to survive; however, initial kill rates are variable. The effectiveness of this method will depend on the suitability of available fuel loads, litter moisture content, fire intensity, temperature, relative humidity, soil moisture and season (Bradstock & Gill, 1993). Furthermore, the elimination of competing native plant species (native plant species that are not fire tolerant) and increases in soil nutrients following burning (since burning can promote the release of nutrients from organic matter).

Prevention of invasive alien invasive species is the most effective management strategy because it minimizes the risks (like environmental) associated with utilization of other methods (for example chemicals) and reduces management costs. According to CBD (2009), prevention of invasive alien species includes regulating intentional introductions and minimizing unintentional introductions (through the identification of potential high-risk species and corridors) and the measures to prevent their establishment can be applied pre-border (before it leaves the source country), at the border (as it enters a country), or post-border (once it is already within a country).

2.7.3. Application of chemical, mechanical and biological control

The numerous herbicide treatments can be used and are said to be effective when applied as a foliar spray or to the base of the stems and cut stumps. Biological control can be considered relatively as the best and most desirable control option for the control of invasive alien species but it will not be influenced by constraints (because the other management options like mechanical and chemical are dependent on the land use, extent and density of the invasive populations, accessibility to invaded areas, economic value of land, and the associated costs) (Day et al., 2003). In addition, utilization of chemicals may not only be expensive and difficult but may also result in long-term environmental pollution and possible serious problems which may come upon in the future. Several biocontrol agents (insects) have been released from time to time to manage invasive alien species biologically. The utilization of defoliating herbivores like Teleonemia scrupulosa Stål and Uroplata girardi Pic (since leaf defoliation can result in decreased seed production and dieback of leaves and some branches) can be used to remove and control the species dispersal.

Invasive alien plants are a problem of global significance, causing impacts running into billions of dollars annually. Impacts associated with invasive alien plants include reduced surface water runoff and groundwater reserves, increased biomass and fire intensity, markedly reduced biodiversity and many economic consequences. Mechanical control usually refers to the mowing or mechanical cutting of an invasive plant infestation to limit seed production. With mowing, timing is essential. Invasive plants must be removed before the plants go to seed in order to be an effective method of control. When fire is used, it can be applied in conjunction with physical control (for example fell and burn, or burn and follow-up with hand weeding). The equipment used in mechanical control ranges from hand-held instruments

![Figure 6. Social impact assessment framework, adapted for application to invasive species management (Sarah et al., 2016).](image-url)
(such as saws, slashers and axes) to power-driven tools such as chainsaws and brushcutters, and even to bulldozers in some cases. Mechanical control is labour-intensive and thus expensive to use in extensive and dense infestations, or in remote or rugged areas.

2.8. **Impacts of current climate change and variability in Ethiopia**

Climate-related hazards in Ethiopia include drought, floods, heavy rains, strong winds, frost, heat waves (high temperatures), lightning, etc. Though the historical social and economic impacts of all of these hazards are not systematically well documented, the impacts of the most important ones; namely, droughts and floods.

The major adverse impacts of climate variability in Ethiopia include:-.

- Food insecurity arising from occurrences of droughts and floods;
- Outbreak of diseases such as malaria, dengue fever, water-borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts;
- Land degradation due to heavy rainfall;
- Damage to communication, road and other infrastructure by floods

Invasion of invasive alien species is among the most important global-scale problems experienced by natural ecosystems. Even though this biological invasion is a natural process, the recent accelerated rate of invasions is clearly anthropogenic phenomenon and constitutes one of the most important effects that humans have created on the earth (Sharma et al., 2005).

Invasive Alien Species are species which are introduced unintentionally or intentionally into a natural environment where they are not normally found, with serious negative consequences for their new environment. Such species are also termed environmental weeds and may alter ecosystem structure and function (Grice, 2006; Minchinton et al., 2006).

The unusual increase in the movement of these invasive alien species due to various reasons such as increased transport, trade, travel has accelerated their rate of introduction everywhere and these activities provide pathways for these species to cross biogeographical barriers that would usually block their way, with harmful consequences on native biological diversity (Genovesi and Shine, 2004). Like many other countries in the tropics, many invasive alien species have been introduced to Ethiopia. Among the introduced invasive alien species 35 have been so far identified (Tamiru, 2017). From the so far identified invasive alien species Parthenium hysterophorus, Prosopis juliflora, Eichhornia crassipes, Euphorbia stricta, Mimosa diglotricha, Xantium strumarium and Lantana camara L. are the foremost ones; which are a pronounced concern in Ethiopia that are posing particular problems on biodiversity, agricultural lands, rangelands, national parks, waterways, lakes, rivers, power dams, roadsides and urban green spaces with great economic and ecological consequences (Seifu et al., 2016; Tessema et al., 2009).

2.8.1. **Vulnerability to climate change of smallholder farmers**

Climate change as an environmental issue affects all aspects of human life, as Varela-Ortega et al. (2013) suggested, including the environment and social communities. The agricultural sector is most sensitive to changing climatic conditions (Menike and Arachchi, 2016) which affect agricultural production and farming communities. Smallholder farmers are one of the most vulnerable social groups to climate change (Lindoso et al., 2012), especially in developing countries. Climate change is expected to alter pest and disease outbreaks, increase the frequency and severity of droughts and floods, and increase the likelihood of poor yields, crop failure and livestock mortality (Harvey et al., 2014; Morton, 2007). Considering the close relationship between agricultural production and household income of smallholder farmers, the negative impact of climate change on crop yield increases the vulnerability of farmers. Therefore, climate change not only has an impact on agriculture production of farmers but it also puts their household well-being and food security at risk (Alam et al., 2017). Their study identified a number of farm level adaptation methods employed by farmers households that include changes in crop variety, crop types, planting dates and input mix, depending upon the nature of the climate-related risks. Their results revealed that to increase resilience against climate change, agricultural policies should shift from maximizing agricultural output to stabilizing it.

There are different definitions of vulnerability to climate change (Thornton et al., 2006; Reed et al., 2013) whilst there is little consensus about its precise meaning. Intergovernmental Panel on Climate Change (IPCC, 2000) stated that vulnerability is: “the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.” Thus, vulnerability of any system is frequently considered as a function of three elements:
exposure to a hazard, sensitivity to that hazard, and the capacity of the system to cope with and adapt or recover from the effects of those conditions (Smit and Wandel, 2006; Reed et al., 2013), which are mostly referred to as adaptive capacity. Also, (Chinwendu et al., 2017) argued that vulnerability is a degree of risk and inability to resist to climate deviations. The relationship among these three components is outlined schematically in Figure 7.

2.8.2. Invasive species, climate change and ecosystem-based adaptation

Individually, climate change and invasive species present two of the greatest threats to biodiversity and the provision of valuable ecosystem services. Combined, the complexity of the interaction of these two global drivers climate change and invasive species increases dramatically, and evidence is rapidly growing on how climate change is compounding the already devastating effects of invasive species. Climate change impacts, such as warming temperatures and changes in CO₂ concentrations, are likely to increase opportunities for invasive species because of their adaptability to disturbance and to a broader range of biogeographic conditions and environmental controls. The impacts of those invasive species may be more severe as they increase both in numbers and extent, and as they compete for diminishing resources such as water. In addition to range expansion, there may also be range contraction or diminished impacts of invasive species pending the influence of climatic and other variables (Richardson et al., 2000; Hellmann & Byers et al., 2008).

From a food security perspective, there is little point in addressing the impacts of climate change on the productivity of a staple food if the crop has already been decimated by an invasive pest. Similarly, from a conservation perspective, there is little point to addressing climate change if the biodiversity we’re trying to protect has already been lost to invasive species. Major agricultural outbreaks or health pandemics could result in significant human suffering and loss. Ecosystem-based adaptation is gaining attention as a cost-effective means of protecting human and ecological communities against the impacts of climate change (Heller & Zavaleta, 2009; Mooney et al., 2009; World; Bank, 2009). Ecosystem based-adaptation is described as building nature’s resilience to the impacts of climate change, while also helping to meet people’s basic needs. Invasive species can threaten those basic needs and compromise ecosystem functions by taking advantage of habitat disturbance, species under stress and other chinks in the armor of otherwise healthy systems. Such ecosystem-based approaches are thereby not simply about saving ecosystems, but rather about using ecosystems to help “save” people and the resources on which they depend. Such an approach can also provide an integrative framework to address impacts from both climate change and invasive species.

2.8.3. The role of climate change adaptation and mitigation in invasive alien species

From a policy perspective, invasive species and climate change issues have largely been kept separate, however, it is increasingly apparent that they will require integration particularly around the common priorities identified below. It should be clearly stated that the

![Figure 7. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity (Tao et al., 2011).](image-url)
management of invasive species can be a key tool for ecosystem-based adaptation under climate change as it can reduce one of the major stressors on ecosystems and their services in and of itself, while also reducing the potential for additional greenhouse gas emissions caused by the impact of invasive species. First, climate change will almost certainly lead to changes in the distributions of species (Parmesan, 2006). The removal of temperature or moisture constraints to dispersal and survival will allow species to move into and successfully invade new areas (Hellmann & Byers et al., 2008).

**Climate change adaptation management plans and activities**, particularly those focused on ecosystem-based adaptation, should incorporate invasive species management as a key tool to reduce pressure on key ecological services and to enhance ecosystem resilience. Prevent the introduction and establishment of new non-native species to minimize the possibility of future invasions and their subsequent impacts. Moreover, to eradicate or control any existing invasive species (including damaging native species) with the potential to fundamentally alter ecosystem composition and services, thereby enhancing ecosystem resilience. Assess the potential for biological invasion associated with the development and construction of adaptation practices particularly those designed to meet key human needs (e.g. water distribution systems, aquaculture facilities, shifts in agricultural practices).

**Climate change mitigation plans and activities**; should not create new or exacerbate existing biological invasions can include the following key activities. Assess the potential for biological invasion in the cultivation of particular species (e.g. intentional introductions for biofuels) or the development and construction of particular sequestration technologies (e.g. unintentional introduction or spread through energy infrastructures, ocean fertilization practices). Eradicate or control damaging species with the potential to reduce the carbon sequestration ability of ecosystems to sequester carbon.

### 2.9. Impacts and challenges of climate change and invasive species on food security

Invasive species are a major cause of crop loss and can adversely affect food security. There has been no evaluation of total invasion threat and its potential cost to agricultural crop production from a global pool of potential invasive species considering all countries at risk. As food security is challenged by climate change and invasive species, the management of these threats will also become more difficult. Similar changes in the success of other management strategies, such as fungicides, insecticides and biological control, are also possible under climate change (Chakraborty et al., 2000). An increase in chemical application or a required switch to another strategy may have corresponding economic costs that may be prohibitive to small-scale farmers (Gay et al., 2006). There is a substantial lack of research investigating the interactive effects of climate change and invasive species on agriculture, especially on projected rates of change and basic climate data for major agricultural and forested areas (FAO, 2008b). Encroachment of rangelands by invasive species, reduction of crop yield, genetic erosion of biodiversity, disruption of water flow, poisoning of livestock, formation of impenetrable thickets, etc. are some of the impacts of invasive species across a wide range of agro-ecologies. They are considered one of the key pressures on world’s biodiversity: altering ecosystem services and processes, reducing native species abundance and richness, and decreasing genetic diversity of ecosystems (Kathiresan et al., 2005).

The clearly negative consequence of invasive species is their threat to native species as a whole. Invasive species may directly reduce the number of native species, reduce the number of other species relying on local species, lower the ability of native species to resist pests and fire, and alter mechanisms of soil and water conservation. Because most native species and environments do not have established economic values, it is difficult to mobilize support in their defense. Invasive alien species of plant are accidentally or intentionally introduced in to the country are subsequently escaping from their entry points and their spread is increasing at alarming rate from time to time. Even in the absence of precise figures, it is clear that the spread of invasive alien species in Ethiopia has increased in the last decade, both in terms of area coverage and plant density (Sertse, 2005). Invasive species are of concern because of their capability of spreading fast, their high competitiveness and ability to colonize new areas within short periods. The nature and severity of the impacts of these species on society, economic life, health and national heritage are of global concern (McNeeley et al., 2001).

### 3. Conclusion and recommendation

Based on the background justification and some related to the literature reviews of the study, the following conclusion and recommendation were forwarded to climate change intensification impacts and challenges of invasive species and adaptation measures in Eastern Ethiopia. Invasive species cause socio-economic and ecological impacts and are part of key challenges of global intervention. *Prosopis juliflora*, an evergreen tree/bush, is a powerful exotic invader in Ethiopia. Invasive alien species are characterized by rapid
reproduction and growth, high ability to disperse and survive on various food types and in a wide range of environmental conditions. The major Types of Invasive Alien Species are Parthenium hysterophorus L., Eichhornia crassipes (Mart.) Solms, and Prosopis juliflora (Sw.). These species are a global threat to food security and livelihoods can affect crop production, animal husbandry, human health and biodiversity species. Prosofis juliflora impacts and driver pastoral vulnerability include changing local environments, where reduced biodiversity, loss of livestock forage and fodder and loss of culturally valuable indigenous species. Furthermore, climate change leading to increased invasive insect, disease and weed pests from pesticide and herbicide which reductions in yield. The major adverse impacts of climate variability in Ethiopia include food insecurity arising, outbreak of diseases, land degradation, increase the opportunities for IAS adaptability to disturbance. Smallholder farmers are one of the most vulnerable in climate change expected to alter pest and disease outbreaks, increase the frequency and severity of droughts and floods, and increase the likelihood of poor yields, crop failure and livestock mortality.

Generally, in eastern Ethiopia, there is a lack of clear documentation, insufficient information regarding the invasion rate and impacts, a lack of financial resource conducting research on the adaptation measure of Prosopis juliflora. Climate change adaptation should prevent the introduction and establishment of new non-native species to minimize the possibility of future invasions and their subsequent impacts. Climate change facilitates and create opportunity for the establishment and spread of invasive species and also reduces the resilience capacity of native species. Therefore, invasive alien species have received insufficient recognition in climate change related and there is a narrow gap between climate change and invasive species that accelerate impacts of social and environmental issues.

outbreak of diseases, land degradation due to heavy rainfall. Negative environmental and economic impacts caused by the species will be high if preventive and effective management measures are not seriously taken, and it becomes one of the major challenges of our century. Therefore, national effort is organized towards combating P. juliflora expansion.

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**PUBLIC INTEREST STATEMENT**

Prosopis is one of the world’s worst invasive alien species, causing severe environmental degradation to arid and semi-arid lowlands of the Horn of Africa and threatening the livelihood and food security of pastoral and agro-pastoral community. This Invasive Species is a serious invader, causing great ecological and economic damage in eastern Ethiopia. Prosofis juliflora impacts and driver pastoral vulnerability and agricultural lands where reduced biodiversity, loss of livestock forage and culturally valuable of indigenous species. The major adverse impacts of climate variability in Ethiopia include food insecurity arising from droughts and floods.
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