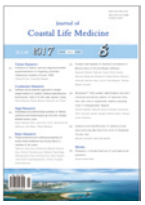
Journal of Coastal Life Medicine

journal homepage: www.jclmm.com



Original article https://doi.org/10.12980/jclm.5.2017J7-26

Invasion and impacts of *Xanthium strumarium* in Borena Zone of Oromia Region, Ethiopia

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ARTICLE INFO

Article history:
Received 9 Feb 2017
Received in revised form 8 May, 2nd revised form 9 May 2017
Accepted 15 Jul 2017
Available online 11 Aug 2017

Keywords:
Xanthium strumarium
Invasive
Biodiversity
Impact

ABSTRACT

Objective: To assess the impacts, mode of entry, trends, status, distribution and management practices of *Xanthium strumarium* (*X. strumarium*) in Borena Zone of Oromia Region.
Methods: Four study districts and eight kebeles (peasant associations) were purposively selected based on distribution level and data from agricultural offices. Then, randomly, eight key informants were selected from each kebele. Data were collected using semi-structured interview and analyzed using SPSS version 21.
Results: All respondents (100%) acknowledged that *X. strumarium* highly invaded the study area and its spread was increasing both in time and space. According to respondents, *X. strumarium* was introduced to the area mainly along with improved seed varieties, food aid, flood, animals and vehicles, and easily dispersed by clinging to animal hides and human clothing. In the past time, *X. strumarium* caused high level of damage on native biodiversity and thus respondents worried that this might continue in the future. Similarly, respondents (98.4%) stated that *X. strumarium* was out of control in the study area and they recommended further investigation by concerned body to control the spread.
Conclusions: In conclusion, *X. strumarium* is spreading rapidly in the study area by threatening native biodiversity and adversely affecting agroeconomy of the farmers and the country. Therefore, it needs the effort of all concerned bodies to control the impacts.

1. Introduction

An invasive alien species (IAS) is a species that is introduced from outside of its past or present natural range of distribution either by intentional or unintentional human activities. It may include gamete, seed, and egg of such species that might survive and subsequently reproduce. In addition to human related introduction mechanisms, extraordinary increase of wild species movement has been accelerating the rate of introduction, with deleterious consequences on native biodiversity[1].

In Ethiopia, IAS are posing major problems on native biodiversity including agricultural lands, rangelands, national parks, waterways, lakes, rivers, power dams, roadsides and urban green spaces with great economic and ecological consequences[2,3]. Like other countries in the tropics, hundreds of alien species has been introduced to Ethiopia. Some of these are IAS including *Parthenium* (*Parthenium hysterophorus*), *Prosopis* (*Prosopis juliflora*), water hyacinth (*Eichhornia crassipes*), cactus (*Euphorbia stricta*), *Mimosa diplotricha*, *Xanthium strumarium* (*X. strumarium*) and lantana weeds (*Lantana camara*)[2,4].

X. strumarium is a common monoecious annual herbaceous plant species belonging to Asteraceae family[5]. More than sixteen *Xanthium* species have been identified and the most common are *X. strumarium* and *Xanthium spinosum*. They are supposed to be originated from Central and North America and distributed worldwide[5,6]. There is wide variation, both within *Xanthium* populations in fruit size, pubescence, the number and length of spines and the degree to which the beaks and spines are hooked[7]. However, all *Xanthium* taxa are tetraploid (with 2n = 36). *Xanthium spinosum* is more homogeneous throughout its range than *X. strumarium* and there may be hybrid between them[5].

X. strumarium germinates at a wide range of temperature and can invade large areas of wetlands. It is the major troublesome weed of row crops such as soybeans, cotton, maize, corns and groundnuts in many parts of the world[8,9] causing the highest reduction in yield of all annual weeds[10]. It invades pastures and grazing lands causing reduction in forage production and poisoning domestic animals

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The journal implements double-blind peer review practiced by specially invited international editorial board members.

which affect livestock production[11,12]. The prickly burs can cause considerable discomfort to animals by clinging to hair on the legs and matting the tails and manes of horses. The toxic compound (carboxyatractyloside) causes vomiting, muscular spasms, liver degeneration and occasionally death in animals[12].

X. strumarium is one of the 35 IAS posing negative impacts on the country's biodiversity. Currently, it has been identified as one of the top invasive plant species which are distributed in a wide range across the country[3,13]. In Ethiopia, its distribution status is very high, but little is known about biological, ecological mechanisms of invasion, impacts, and management options of this invasive plant. Therefore, this research aimed to assess the impacts, mode of entry, trends, status, distribution, and management practices of *X. strumarium* in Borena Zone of Oromia Region, Ethiopia.

2. Materials and methods

2.1. Description of the study area

Borena Zone is located in 3°26'–6°32' N latitude and 36°43'–40°46' E longitude extending for about 331.6 km north to south and 442.06 km east to west. The zone shares common boundaries with Somali Region in southeast, Southern Nations, Nationalities and Peoples' Region in the north and west and 521 km international boundary with Kenya. Borena Zone consists of 13 districts (woredas), namely, Yabelo, Teltele, Dire, Miyo, Moyale, Arero, Dugda Dawa, Gelana, Abaya, Melka Soda, Dillo, Dhas and Bule-Hora (Figure 1). The zone comprises 10% temperate, 20% sub-tropical and 70% tropical climatic conditions. The largest area of the zone is settled by pastoral, agriculturalist, and semi-agriculturalist.

The major areas of the zone (altitude below 1 500 m above sea levels) found in the low land areas can be categorized as "Gomojji" with semi-arid climate. These wide areas are found in the southwest and eastern parts of the zone. These include Moyale, Dire, Arero, Gelana and Abaya (western part) and Yabelo. The high lands (over 1 500 m above sea level) are found in north central and southern parts which include Abaya, BuleHora, Yabello and central parts of Dire. Yabello Mega plateau, the extension of southern highland which rises to 2 000 m and some of highland of BuleHora with an altitude over 2 500 m asl are known as mountains of the zone.

2.2. Data collection

Questionnaire based survey using semi-structured interview and field observation was employed to generate data for this study. The questionnaires were prepared in English and then translated into local language. The whole processes were administered with the help of trained interpreters who well understood the objectives of the study.

Four study districts were selected purposively based on the level of *X. strumarium* invasion and information from agricultural offices of the region. From each district, two representative kebeles were selected, similarly based on the level of invasion.

Eight key informants were selected purposively from each kebele and a total sample size (64) was obtained. The key informants were selected with the help of local administrators or kebele leaders and developmental agents. The selected key informants were interviewed about impacts, trends, mode of entry, spread, status, distribution and

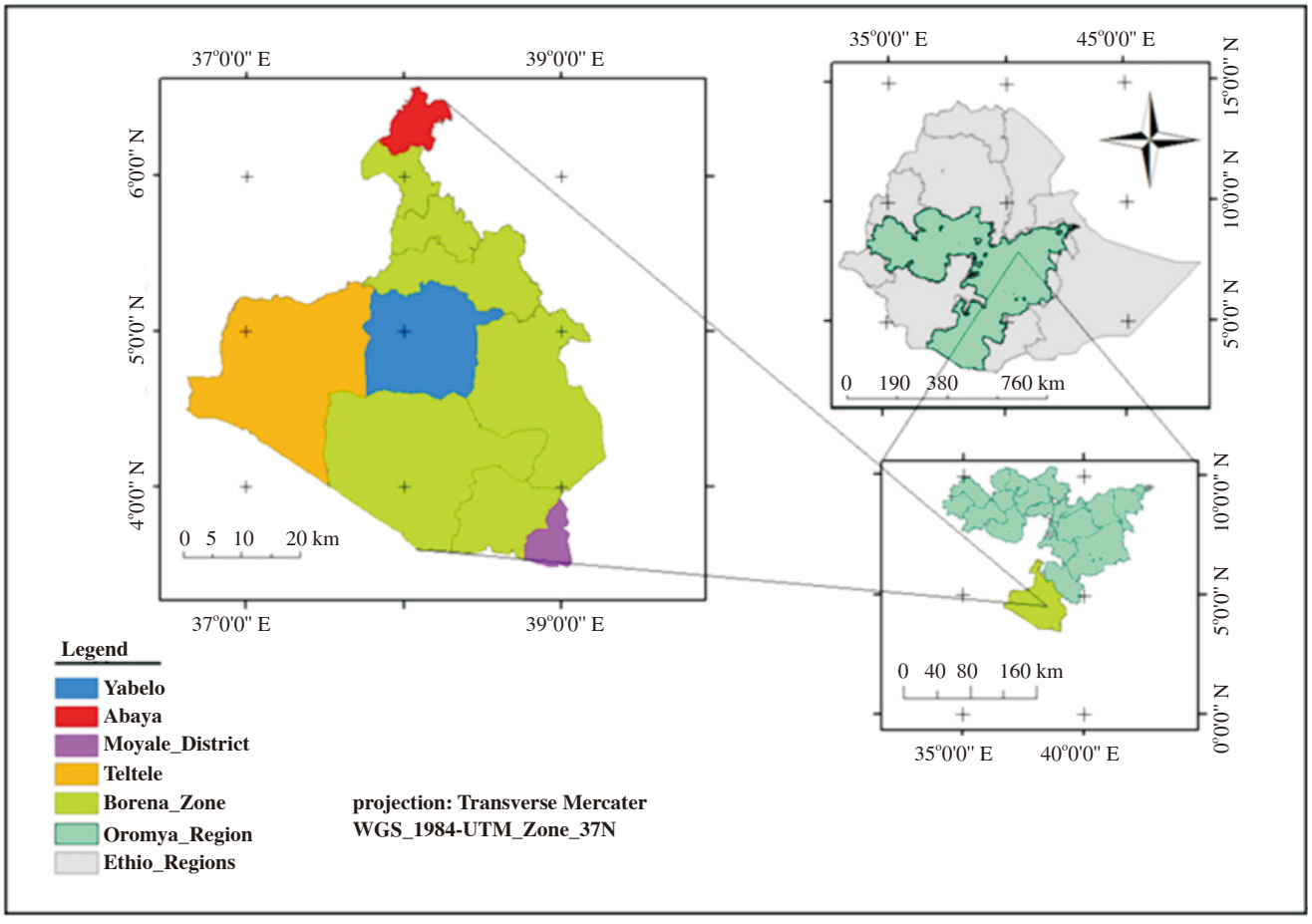

Figure 1. Administrative map of the study area.

management practices of *X. strumarium*.

2.3. Data analysis

Data were analyzed using SPSS (version 21). A descriptive statistical method was employed to analyze and summarize the data as well as to calculate percentages, frequencies, and means.

3. Results

3.1. Sociodemographic characteristics

A total of 64 respondents, 55 (85.9%) males and 9 (14.1%) females, were interviewed from September 2016 to October 2016. The age of respondents varied between 25 years (the minimum age) and 80 years (the maximum age) with mean age of (43.47 ± 15.45) years. Ninety-eight percent of the respondents were married and all of them were living in the study area for more than 9 years. Out of the total respondents, 44 (68.75%) were native to the study area and the remaining 20 (31.25%) were resident. Regarding to their education status, 29 (45.3%) were unschooled, while 35 (55.7%) had attended either primary or secondary school education.

3.2. Level and status of X. strumarium

All respondents (100%) agreed that they were conscious about the invasiveness of *X. strumarium*. In Moyale District, Yabello, Teltele and Abaya, respectively, 75%, 87.5%, 62.5% and 93.8% of the respondents agreed that the invasion of *X. strumarium* was very high. This was also confirmed by personal observation of researchers during the study period (Figure 2). The whole respondents (100%) also noticed that the status of invasion of *X. strumarium* was increasing from time to time and 98.4% (63/64) stated that it was getting out of their control.

3.3. Mode of entry and spread of X. strumarium

Respondents emphasized that the following were the mechanisms of introduction of *X. strumarium* in the study area, with improved seed varieties (32.8%), food aid and transport materials (25%), and flood and animals (23.4%). However, 18.8% of them informed that they had no information about how *X. strumarium* was introduced. On the other hand, the fruits clung to the hide of animals and human clothing and easily transported from place to place (Figure 3).

Forty-five percent of respondents had no information about where *X. strumarium* was introduced. However, majority of them perceived that *X. strumarium* had been introduced to the study area from Kenya (21.9%), Somalia (1.6%), or from countries where improved seed varieties (29.7%) and road construction materials come (1.6%).

There were different reactions from respondents regarding the time when *X. strumarium* was introduced to their local area. From the total respondents, 70.3% stated that it was introduced to their local area before 10 years ago. Whereas, 12.5% thought that it was introduced to their lands before 20 years ago. The remaining 17.2% claimed that *X. strumarium* was introduced before 41 years ago. Although, there was disagreement among respondents regarding to the time of invasion, the whole respondents (100%) from all the study districts agreed that *X. strumarium* was non-native invader plant (invasive alien plant species) that was introduced and rapidly spread by threatening the ecosystem, economy and the society.

Regarding to the mechanisms of spread, 92.2% of respondents informed *X. strumarium* was easily dispersed by flood, animals, wind, vehicles, and human clothing. The remaining 4.7% and 3.1% related the mechanism of spread to the presence of many seeds per individual plant and the long dormancy period of the seeds, respectively.

All respondents (100%) informed that agricultural fields, disturbed lands and wet lands were the main habitats which were mostly invaded by *X. strumarium*. Of this, 79.70% informed that *X. strumarium* was mainly found on their agricultural field and the

Figure 2. Status of *X. strumarium* in the study area.

remaining 18.80% and 1.60% informed that it was abundant in all ecosystem and disturbed lands, respectively (Table 1).

Figure 3. *X. strumarium* fruits cling to the hide of animals (a photo taken during field survey).

Table 1
Ecosystems/areas that are highly invaded by *X. strumarium* (%).

Districts of the respondents	Agricultural fields	Disturbed lands	All type of ecosystems	Total
Moyale	68.80	0.00	31.30	100.00
Yabelo	75.00	6.30	18.80	100.00
Teltele	75.00	0.00	25.00	100.00
Abaya	100.00	0.00	0.00	100.00
Total	79.70	1.60	18.80	100.00

3.4. Impact of X. strumarium

All respondents (100%) stated that *X. strumarium* had been imposing threats to the community by causing human and animal injury, invading agricultural lands, and competing with native biodiversity. They also informed that it had been agitating their time to clean the agricultural field. As informed by all respondents (100%) and based on observational survey, *X. strumarium* was causing massive negative impacts on the biodiversity of the study area.

Regarding to the crops that were highly harmed by *X. strumarium*, 75% of the respondents listed maize (*Zea mays*), common bean (*Phaseolus vulgaris*), mustard (*Brassica carinata*), and teff (*Eragrostis tef*) as those that were highly affected by *X. strumarium*. The remaining 25% argued that all plants were highly affected by *X. strumarium* either preferentially or equally. In general, the following plants were listed by informants as plants which were commonly weeded by *X. strumarium*: maize (*Zea mays*), common bean (*Phaseolus vulgaris*), mustard (*Brassica carinata*), teff (*Eragrostis tef*), bread wheat (*Triticum aestivum*), sweet potato (*Ipomoea batatas*), peanut (*Arachis hypogaea*), barley (*Hordeum vulgare*), chickpea (*Cicer arietinum*), and lentil (*Lens culinaris*).

3.5. Economic impacts

X. strumarium had great damaging impacts on the annual yield and the economy of farmers. In average, the farmers lost (11.48 ± 15.23) thousands of Ethiopian birr per year per hectare (Figure 4).

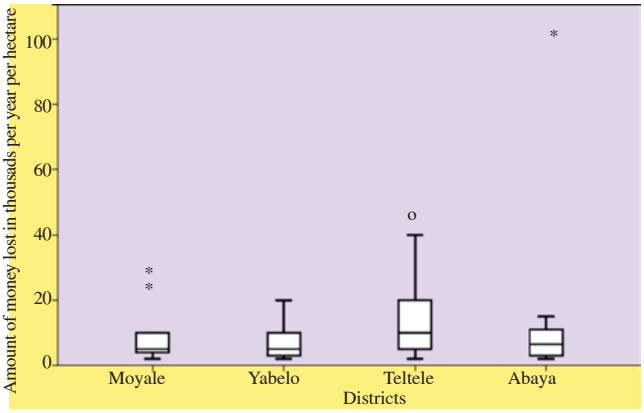

Figure 4. Estimated amount of money (Ethiopian birr) lost because of *X. strumarium* per year per hectare.

All interviewed individuals stated that *X. strumarium* had caused a high level of damaging impacts on biodiversity in the past time; and they informed that the level of damaging impact had been increasing slightly and severely through time. Of this, 87.5% informants preferentially explained that the level of damaging impacts of *X. strumarium* had been increasing severely. Only two individuals argued for the decrement of the level of *X. strumarium* negative impacts on biodiversity in the past time. Respondents also agreed with the widespread and overall coverage of the negative impacts of *X. strumarium* on biodiversity in the study areas during the past time. The pattern of agreement regarding to *X. strumarium* negative impact coverage was localized spread (10.9%) and throughout spread (89.1%). All respondents (100%) worried about its negative impacts on biodiversity in the future. From the total respondents, 10.9% and 89.1% agreed that it would impose either moderate or very severe negative impacts on biodiversity in the future, respectively.

3.6. Management practices

From the total respondents, 9.4% reported that the local community was trying to control the spread of *X. strumarium* by cutting at young stage and burning it. However, majority of them (56.3%) were trying to control its spread by digging out and burning at young stage. The remaining 32.8% used any technique which they thought was appropriate to control *X. strumarium*. Regarding to the effective techniques or practices applied by the local community to control the spread of *X. strumarium*, 51.6% of the respondents mentioned that they used manual/mechanical methods (digging out and burning) to effectively control the spread of *X. strumarium*. Whereas, 48.4% of the respondents replied that there was no effective control method.

4. Discussion

The results of this study showed that the nature and characteristics

of *X. strumarium* were responsible for its wide invasion and challenges to manage. The active seed dispersal mechanism, being drought resistant, having long dormancy period, and production of many seeds (400 to 500 fruits) which can be easily attached and transported by animals, humans and flood are responsible for the challenges[12,14]. Heavy output of *X. strumarium* seeds coupled with their viability and germination under varied environmental conditions were shown to be responsible for its aggressiveness and wide spread both in space and time[7,15]. *X. strumarium* grows faster having short life cycle, greater reproductive potential, competitive ability and allelopathy that make it successful invader[16]. The fruits cling to the hide of animals and human clothing and easily transport from place to place. This is very problematic in areas (such as the present study area) where there is high population of livestocks. In riparian habitats, fruits on the soil surface may later be dispersed by water as they float for up to 30 days and seed viability is usually high which can range more than 80 percent[12,14]. The large seed is non-dormant and typically germinates the first spring following production, while the smaller seed germinates later in the season or, more frequently, the following year[12]. Occasionally, the two seeds germinate simultaneously. Depth of burial also influences germination. Seeds lying on the soil surface and those buried more than 6 inches (15 cm) below the soil surface rarely germinate. Such variations allow the plant to germinate in various seasons as indicated by informants.

Studies also showed the seeds of *X. strumarium* are encased by a hard, woody bur thus insulated from the heat of fire and they have innate dormancy for 1 or more years[17]. Similarly, it was observed that seeds produced in large quantities tend to fall near the parent plant producing dense stands. The plant is known to break off at the base and be windblown for long distances helping to disperse seeds. The immense numbers of produced seeds evince the high propagation of the species. The *Xanthium* species is characterized by its high propagation ability that affects to a large extent the rangeland ecosystems[12]. The appendages and sticky nature of fruits facilitate their mechanical dispersal by animals including human beings. Fruits and seeds of many plants including *Xanthium* are provided with hooks, barbs, spines, or stiff hairs so that if animal grazes or brushes against them, these stick to the animal's body or grab (clothing). Later on, these drop off somehow or other are thereby dispersed. The fruits of *X. strumarium* are provided with hook like structures effective in their dispersal[14].

The study also revealed that *X. strumarium* is noxious non-native invader plant (invasive alien plant species) that is introduced and rapidly spreads by threatening the ecosystem, economy and the society. The reports of different authors also agreed with this claim: for instance, Stesevic and Petrovic[6], and Dekker[5] who reported that *X. strumarium* was originated from Central and North America and then distributed throughout the temperate and subtropical regions of the world.

The results of this study showed that agricultural fields, disturbed and wet lands are the main habitats which are mostly invaded by *X. strumarium*. The plant is an annual weed found throughout the temperate and subtropical regions of the world and occurs in areas such as ruderal habitats, waste places, agricultural fields[7,12,14], and along watercourses, beaches and coastal dunes. Many more findings also indicated that it occasionally forms a dominant ground cover in open riparian woodlands, intermittent streambeds, and beach habitats.

X. strumarium can tolerate a variety of soil conditions ranging from moist clay to dry sand but grows best on compact sandy soil that is slightly moist below the soil surface and contains a small amount of organic matter[7,12]. It also tolerates flooding at all growth stages. Similarly, it is able to grow in different types of habitat such as cultivated fields, vacant lots, sandpits, and dry washes, on beaches and sand dunes, and along the shores of ponds and rivers, especially riverbeds left barren by receding floodwaters[12,17]. Therefore, such ecologically diversified adaptability of *X. strumarium* allows its rapid expansion and speeds up the damaging impacts on animal/plant products, resulting in monoculture formation and native biodiversity reduction.

This study showed that *X. strumarium* has been threatening to the community by posing injury on human and animal, invading agricultural lands, and competing with native biodiversity. It has been affecting fundamentally economical and nourishment crops such as *Zea mays*, *Phseolus vulgaris*, *Brassica carinata*, and *Eragrostis tef*. As the community (the country in general) basically depends on these crops, the damaging impacts of *X. strumarium* together with other invasive alien plant species may cause irreversible loss, which might aggravate the risk of famine and hardship conditions. In the present time, it was recorded as a principal invasive weed of many vegetable and crop fields in various countries including India and South Africa, Zimbabwe[14,18,19] and not only is the native plant communities were affected by the invasiveness of this plant species but also the fauna. The burs cause an allergic reaction in some people and are toxic to many animals[7,11]. Poisoning threats are greatest in areas where other, more palatable plants have already been consumed. It reduces the yield of many cereals such as wheat as its seed is an undesirable contaminant in stock sold food, in turn, a high level of control is required. As the present results showed, it often occurs in dense strands in agricultural fields and natural habitats where it can compete and potentially displace native biodiversity. In this condition, besides being competitive weeds in agriculture, as *Xanthium* species are toxic, the seeds can also be confused with those of mustard and can lead to illness and even death after consumption[12,17]. Many more previous findings support the results of present study. For instance, Hussain *et al.*[10] reported row crops such as soybeans, cotton, maize, corns and groundnuts are mainly weeded by this invasive plant in many parts of the world. In groundnuts, *X. strumarium* has been reported to cause yield losses of 31%–39% at a density of 0.5 plants and 88% at 4 plants per m of row in USA. Yields of maize have been reported to decrease by 10% at 1 *X. strumarium* per m of row, to a maximum yield loss of 27% at a density of 4.7 cockleburs per m of row[10]. The allelochemicals from this plant negatively affect crops like onion (*Allium cepa* L.), sunflower (*Helianthus annus* L.) and some vegetables[20]. The leaves and stems extracts of *X. strumarium* significantly reduce germination and seedling growth in corn (*Zea mays* L.), canola (*Brassica napus* L.), sesame (*Sesamum indicum* L.), lentil (*Lens culinaris* Medic.) and chickpea (*Cicer arietinum* L.). Similarly, potassium carboxyactractyloside, a glycoside isolated from the residues of *X. strumarium* strongly inhibit the coleoptile growth of wheat[9]. The mean germination time in maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), rice (*Oryza sativa* L.), wheat (*Triticum vulgare* L.) and sunflower was reduced by leaf leaches of *X. strumarium*[21].

The results of this study showed the level and damaging impact of *X. strumarium* on native biodiversity in the past time have been increasing severely through time. *X. strumarium* is one of the 35 IAS posing negative impacts on Ethiopian biodiversity. Currently, it has been identified as one of the top invasive plant species which are distributed in a widespread range across the country[3,13,22]. A recent study by Lemma *et al.* and Belachew and Tessema[13,23] indicated that *X. strumarium* was one of the nine alien plant invaders which dominated on rangelands of Oromia Zone. Similar study in some districts of Amhara and southern regions of Ethiopia also indicated relatively high abundance of *X. strumarium* compared to *Parthenium hysterophorus*, and *Cynodon aethiopicus*[3]. Generally, the Ethiopian ecosystems which are highly affected by *X. strumarium* may include cultivated landmass, roadside, grazing areas, non-cultivated landmass, rural villages, urban area[13].

The invasiveness of *X. strumarium* will be very high in the future as it is highly adaptable to different environments, highly mobile and tolerant to a variety of soil conditions ranging from moist clay to dry sand[12]. This expectation can be verified by the presence of suitable soil type for the growth of *X. strumarium* in the study areas as it best grows on compact sandy soil that is slightly moist below the soil surface and contains a small amount of organic matter[12]. As one of respondents explained emotionally, the rate of spread is along with its damaging impacts on the country's biodiversity and farmers' economy, unless immediate control measure is taken, this invasive plant will be the most challenging enemy in our country.

The result of this study also showed that there is no governmental or nongovernmental organization that has been working on the control of *X. strumarium* in the study areas. However, many policy and strategy documents including the Environmental Policy of Ethiopia and the National Biodiversity Strategy and Action Plan of Ethiopia have acknowledged the severe threat posed by IAS to the country's biological resources and ecosystems as a whole. Additionally, a number of national and sectorial action plans including the Ethiopian Forestry Action Plan and the National Action Plan to combat desertification implementations initiate activities related to IAS. But, there is a major gap between the rate of expansion IAS in the country and the need to take measures to address the problems effectively. Therefore, there should be urgency to take measures to eradicate this invasive species effectively and protect and conserve the country's biological diversity. As indicated by the informants and based on field survey, *X. strumarium* is causing ecological crises, biodiversity deterioration, economic losses, and health problems in the studied areas and nearby zones. Therefore, the government and the nongovernmental organizations should design effective eradication program responding to threats posed by *X. strumarium*. That is why the whole respondents of this study called for further investigation by concerned body and they expected that the government, the communities and the non-governmental organizations work together to control the spread and/or to eradicate from their land.

Many IAS are introduced intentionally or unintentionally for various purposes. However, a lot of threat is linked with the introduction of new species. The awareness on IAS control options is inadequate. This has resulted in several harms experienced only after being invaded by alien species, which do not seem to have an easy solution. Introduction of *X. strumarium* has now become problematic as it invades on natural areas. Currently, *X. strumarium* is invading all types of ecosystem particularly agricultural fields and wet areas of Borena Zone of Oromia Region. This assessment study indicates the severity of the invasion. Therefore, there is a need of better planning to control, manage and eradicate the spread of *X. strumarium* by establishing communication links between regional, zonal, district and kebele agricultural offices. In addition to this, strong local support and commitment from the government and individuals is needed to control, manage and/or eradicate *X. strumarium*.

Conflict of interest statement

We declare that we have no conflict of interest.

Acknowledgments

The people of Borena Zone, Oromia Region who gave us information are gratefully acknowledged. We are grateful to Ethiopian Biodiversity Institute for financial support during field work. We are also grateful to agricultural workers of Borena Zone who helped us in different ways. Finally, we are indebted very much to Moyale, Yabelo, Teltele and Abaya districts farmers for their unreserved willingness to share their time and knowledge with us.

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