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ESCAPE AND NATURALIZATION OF *TAGETES PATULA* IN WESTERN ETHIOPIA

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ABSTRACT: This study was carried out on an introduced ornamental - *Tagetes patula* L., which has escaped cultivation and has been naturalized in Benishangul-Gumuz National Regional State (BGNRS), western Ethiopia. Another introduced ornamental - *Zinnia elegans* Jacq. and the native species - *Bidens prestinaria* (Sch. Bip.) Cufod. were included in some of the experiments for comparison. Pre-prepared semi-structured interviews were administered, on the arrival, spread and impact of *T. patula*. The result showed that the escaped *T. patula* has no negative impact on the daily life of people, except weeding in farmlands. *T. patula* was found associated with species that prefer shade and moisture in semi-natural vegetation. It produces a large number of relatively small propagules and has a seed bank. These characters might enhance its invasive ability and make it a potential threat to grazing fields and natural landscapes in western Ethiopia. The result of fire simulation experiment, however, revealed that fire had an effect on seed germination, as there was no seed germination at higher temperature treatment (120°C/5 minutes). The annual fire occurring existing in the woodlands of BGNRS might not allow invasion by the species that are not adapted to fire, like *T. patula* and *Z. elegans*. In the absence of annual woodland fire, invasion of the woodland vegetation in BGNRS by *T. patula* and *Z. elegans* is most likely to occur.

Key Words /Phrases: Fire, invasive species, propagules, soil seed bank

INTRODUCTION

Plant species have been and are being introduced all over the world to meet the ever increasing society needs. Many of the major crops that sustain the human population have been introduced species (Pimentel *et al.*, 2000) and have given clear benefits to humans all over the world (Myers and Bazely, 2003). In addition, ornamentals are intentionally introduced as there is public demand for new and exciting species (Mack and Lonsdale, 2001). This encourages gardeners and horticulturalists to frequently and intentionally spread ornamental plant species (Reichard and White, 2001).

Introductions of alien species in an area might have unexpected consequences in several respects, but a general predictive theory of species invasions is lacking (Peterson and Vieglas, 2001). The species that are useful in some areas are not necessarily a success in other areas. Under unfortunate circumstances, species that have given positive contributions somewhere, may escape proper management and become invading weeds elsewhere (Hailu Shiferaw *et al.,* 2004). Introductions might have serious consequences for ecological, economic and social systems. Once an invasive species becomes established, its control may be difficult and eradication is sometimes impossible (Pimentel *et al.,* 2000). Moreover, the impact of invaders on natural communities, *i.e.*, biodiversity and ecosystem processes, can be serious (Chapin *et al.,* 2000; Hailu Shiferaw *et al.,* 2004). Exotic weeds in conserved areas are increasingly recognized as representing a major threat to the preservation of biodiversity, and can profoundly alter ecosystem structure and function (Cronk and Fuller, 1995). On a regional scale the introduced species may out-compete native vegetation and become annoying or devastating weeds in farmlands. If the ecological conditions are favourable, exotic weeds can become very aggressive in their new habitat (Mack *et al.*, 2000). The reason for this is

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that they often out-compete natural species not adapted to competition. They also lack "natural enemies" such as insects and pathogens that keep them in check in their native habitat.

The actual invasion of an environment by new species is influenced by three factors (Lonsdale, 1999):

1. The number of propagules entering the new environment, *i.e.* propagule pressure;
2. The characteristics of the new species;
3. The susceptibility of the environment to invasion by new species, *i.e.*, invasiveness.

Many invasive plants are efficient seed producers. This contributes to their local reproduction, as well as their potential for dispersal (Gross, 1990). A persistent seed bank might also facilitate invasion.

Whether fire facilitates or suppresses invasion by introduced species is disputed (Myers and Bazely, 2003). Fire may cause extinction of invasive species, but recovery from fire is a balance between immigration and extinction (Collins *et al.,* 1995). The eastern African savannah often burns at least once a year, usually following the onset of the dry season. Subsequent fires are generally patchy because of the discontinuity of fuel, differences in relative moisture and wind intensity (Menassie Gashaw and Michelsen, 2002).

The vegetation of western Ethiopia burns annually and the plants show several adaptations to fire (Jensen and Friis, 2001; Menassie Gashaw and Michelsen, 2002). Much of the natural vegetation in this region is still nearly intact, but the area has generally become more accessible because of increased road development. The spread of any introduced plant species in this kind of environment might have serious consequences.

Most home gardens in BGNRS are dominated by useful plant species, *e.g.,* edible vegetables, spices, tobacco and shade plants. Some home gardens also include ornamental plants such as *Tagetes patula* L., *Canna indica* L., *Lantana camara* L., *Zinnia elegans* Jacq., *Datura metel* L., and *Brugmansia arborea* (L.) Lagerh. The above are all introduced plants. *T. patula* and *Z. elegans*, both in the family Asteraceae, are the only introduced ornamentals which have been noticed outside home gardens, spreading into woodlands. This study was, therefore, conducted to investigate the ecological and biological factors that facilitate escape and naturalization of *T. patula* in western Ethiopia. The introduced ornamental *Z. elegans* and the native species *Bidens prestinaria* (Sch. Bip.) Cufod. were included in some of the experiments for comparison. The findings will hopefully contribute to proper protection of vegetation in BGNRS from introduction and establishment of invasive alien species.

MATERIALS AND METHODS

Study site

The fieldwork was undertaken in Bulen, Dibatie and Mandura districts of BGNRS, western Ethiopia where *T. patula* was found as an escape over large areas (Fig. 1). BGNRS is bordered by Amhara National Regional State to the north, Oromia National Regional State to the east and south, and the Republics of Sudan and South Sudan to the west. The topography of the districts is characterized by a rolling terrain, sloping relatively gently but sometimes dropping steeply from an average of *ca.* 1800 m on the Ethiopian highlands to 500–700 m close to the lowlands of the Republic of Sudan (Sebsebe Demissew *et al.,* 2005). The climate in the region is characterized by a single maximum rainfall, which runs from April/May to October/-November. The average annual precipitation varies from 900 to 1500 mm. The mean monthly minimum and maximum temperatures vary from 14°C to 18°C and 27°C to 35°C, respectively. The variation in the temperature is strongly correlated with altitude (Sebsebe Demissew *et al.,* 2005).

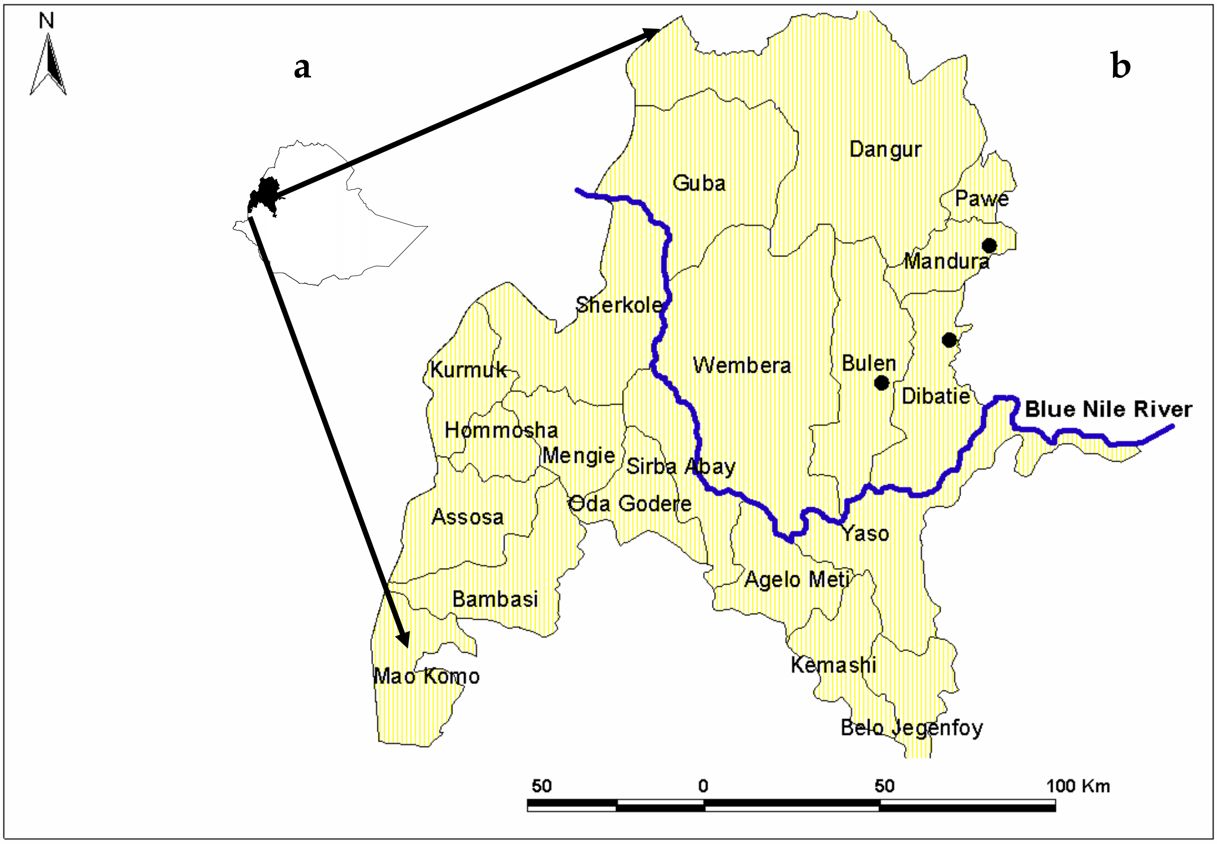

Fig. 1. Map of Ethiopia (a) and Benishangul-Gumuz National Regional State showing administrative districts (b). Sampling sites are indicated by dots.

Target plants

The genus *Tagetes* includes about 50 species which are indigenous in the region stretching from the south-western United States to Argentina and the greatest diversity of the genus is found in south-central Mexico (Mesfin Tadesse, 2004). Three species of *Tagetes* are introduced in Ethiopia. Two of them, *T. patula* (Fig. 2a) and *T. erecta* L. are cultivated ornamentals. The third species, *T. minuta* L., is a noxious weed of farmlands, waste places and roadsides and is found all over Ethiopia (Mesfin Tadesse, 2004). The leaves of *T. patula* are used as a seasoning in central Africa while the dried flowers are sometimes used to adulterate saffron. The whole plant is harvested when in flower and distilled for its essential oils. The oil is used in perfumery and has also a wide range of biological activities (Romagnoli *et al.*, 2005). The plant grows in full sun and, according to Gilman (1999) is not known to be invasive.

a b c

Fig. 2. Inflorescences of the three study species a) *Tagetes patula*, b) *Zinnia elegans* (Photos: Agnethe B. Salvesen**, October 2005) and c) *Bidens prestinaria* (Photo: Tesfaye Awas, October 2005).**

The genus *Zinnia* includes about 23 species and it is native to North America (Mesfin Tadesse, 2004). Only two species, *Z. elegans* and *Z. peruviana* (L.) L. are known to occur in Ethiopia (Mesfin Tadesse, 2004). *Zinnia elegans* (Fig. 2b) is a widely cultivated ornamental plant throughout the world. It is not known to be invasive, but has been recorded as an escape in the central parts of Ethiopia (Mesfin Tadesse, 2004). During this study it was recorded as an escape 31.2 km east of Asosa town in BGNRS.

The genus *Bidens* contains about 340 species and the tropical and subtropical regions of North and South America and Africa are its diversity centres (Mesfin Tadesse, 2004). About 20 species are found in Ethiopia (Mesfin Tadesse, 2004). *Bidens prestinaria* (Fig. 2c) grows in short grassland, gentle mountain slopes, and on river and stream banks. The species is also extending into the margins of arable land and is sometimes found along roadsides from 950 to 2850 m altitude in Ethiopia (Mesfin Tadesse, 2004). *Bidens prestinaria,* which is restricted to Eritrea, Ethiopia, Sudan and South Sudan, was included in this study for comparison.

Data collection

Ethnobotany

A reconnaissance survey was made in July 2004 and vegetation stands that have been invaded by *T. patula* were found in Bulen, Dibatie and Mandura districts of BGNRS. The Gumuz and Shinasha are the indigenous people in the study area. They live along with the Oromo, Agew-Awi and Amhara people.

In October 2005, one site was selected from each district for detailed study. Pre-prepared semi-structured interviews were administered, with extended discussion by taking individual respondents. In the three study sites people were interviewed about the positive and negative effects of *T. patula*, its time of arrival, its use, if it was eaten by animals, if it was actively or passively spreading. Observations were made in home gardens, farmlands, rangelands and natural vegetation. The local name *T. patula* was recorded on the spot when informants reached consensus.

In each household one person (by alternating female and male) was interviewed about the *T. patula*. Informants who were willing to respond to the questions were considered. A total of 66 informants (30 Gumuz, 26 Shinasha and 10 Amhara ethnic groups) were interviewed independently to avoid influence by one another.

Species association study

In each site, two transects were laid from the roadside towards the natural woodland and the percentage cover of all plants in 2 m x 2 m sample plots were recorded following the Braun-Blanquet approach (Braun-Blanquet, 1965; Muller-Dombois and Ellenberg, 1974). A total of 26 study plots were sampled at an interval of 25 m along transects. Hand-held GPS was used to record the altitude, latitude and longitude of each sample plot. All plant specimens were collected and identified by referring to the authenticated herbarium specimens and with the help of written descriptions at the National Herbarium, Addis Ababa University (ETH). All specimens were deposited at ETH and the Institute of Biodiversity Conservation/Ethiopia. The nomenclature used follows Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Phillips, 1995; Edwards *et al.*, 1995; 1997; 2000; Hedberg *et al.*, 2003; 2006; Mesfin Tadesse, 2004).

Seed production

To determine the number of seeds produced per capitula during the fruiting period, all specimens of *T. patula* and *B. prestinaria* in the sample plots were collected. The fruiting capitula of all plants were opened and the number of propagules per head counted.

Fire simulation experiment

The propagules of *T. patula, Z. elegans* and *B. prestinaria* were collected from ripe infructescences for the fire simulation experiment. All the propagules were collected from naturalized or naturally existing plants. The propagules were cleaned and sorted out by selecting the ones without evidence of insect and fungal damage, and then the most mature propagules were chosen for the experiment, which was carried out at the University of Oslo, Norway. About five weeks after collection, ten propagules were randomly chosen from each species and subjected to heat treatment according to six different prescriptions: 60°C, 90°C, and 120°C, for 1 and 5 minutes duration at each temperature. The treatments are denoted as: control (no heat), 60°C/1 minute, 60°C/5 minutes, 90°C/1 minute, 90°C/5 minutes, 120°C/1 minute and 120°C/5 minutes, respectively. These are temperatures likely to be reached at the soil surface or the first few centimetres below the ground during the savannah fires (DeBano *et al.*, 1998). Mechanical scarification and sulphuric acid treatments may be used to simulate fire, and are sometimes preferred to alternative treatments of hot water or dry heat treatments (Cavanagh, 1987). The dry heat treatment was chosen here for comparison with other studies conducted in Ethiopia using the same method (Menassie Gashaw and Michelsen, 2002). Dry heat treatments were accomplished in an oven, with rapid insertion and removal of an aluminium tray containing the propagules. For each species, a total of 350 propagules in five replicates of sets of 10 propagules were used. Untreated propagules were used as control (stored at 20°C), with the same number of replicates. Both the treated and untreated propagules were placed on a wet filter paper in a petri dish. Ten propagules were placed in each petri dish. The petri dishes were placed in a thermo-regulated greenhouse with an average temperature of 26°C during the day (12 h) and 20°C during the night, to create a simulated environment. The filter papers were moistened every day for the first month, and then every third day until the end of the experiment. Seeds were considered to have germinated when the radicle penetrated the seed coat. Germination was recorded daily in the first two weeks, and then every third day. The germinated seeds were removed from the petri dishes. The experiment was terminated after 18 weeks.

Soil seed bank

Soil samples were collected from three sites dominated by *T. patula* and *B. prestinaria.* "Site 1" was a woodland dominated by *T. patula* (6 samples) and situated about two km south of Bulen town in Bulen district, "Site 2" was a hilly area dominated by a combination of both *T. patula* and *B. prestinaria* (5 samples) and situated about one km north of Dibatie town, and "Site 3" was a field dominated by *B. prestinaria* (5 samples) and situated about one km south of Dibatie town. Both "Site 2" and "Site 3" were located in Dibatie district. The soil samples were taken from soil under the target species. The surface of the soil was cleared of weeds and the uppermost layer (*ca.* 0.3 cm) removed. Two fairly close blocks each measuring 10 x 10 cm, 4 cm deep were collected, and bulked. The soil samples were air-dried and roots, rhizomes, tubers, non decomposed litter and plantlets were removed. The soil samples were stored in paper bags and transported to the University of Oslo on 24 October 2005. Then, sixteen potting trays (53 x 32 cm) with holes were filled (half their depth) with a sterile soil. The soil was compressed a bit, and then watered. The soil samples, collected for soil seed bank study, were dispersed on top. The trays were watered and placed in the same greenhouse used for fire simulation experiment. The soil samples were watered once every day. Emerging seedlings were recorded, tagged and placed in pots until they could be identified. All flowering plants grown from the soil seed bank were pressed, identified and deposited at the National Herbarium (ETH) of Addis Ababa University. Mosses were not included in the study.

Data analysis

The percentage cover data on plant species composition were transformed to ordinal transform values (OTV) (van der Maarel, 2005), and analyzed using TWINSPAN, Version 1.0 (Hill, 1979). TWINSPAN is a divisive polythetic method of vegetation classification. It classifies both samples and species. Since four samples (14, 18, 21 and 22) became outliers, it was not possible to determine their exact position, and they were omitted. The number of pseudo-species cut levels was set to 3. The cut levels were 1, 3 and 6. The maximum number of species in the final tabulation was set to 40; in this way rare and common species were excluded from the final ordered two-way table. The default option was used in the rest of the analysis. One Way ANOVA statistics in PALSTAT (Ryan *et al.*, 1995) was used to find out if there was significant variation in germination among the heat treatments.

RESULTS

Ethnobotany

All 66 people who were interviewed explained that *T. patula* had been present in the study area for more than twenty years. In most places it was just called "the plant or a flower ("*Baja*" in Gumuz and "*Funda*" in Shinasha languages, meaning flower). In one location outside Dibatie it was called "*Yederg Arem*" in Amharic (the national language of Ethiopia), meaning "*Derg weed*", where *'Derg'* refers to the military junta that ruled Ethiopia from 1974 to 1991. The main use of the species was as an ornamental and no negative impact was mentioned, except contributing to the weed flora in farmlands. A general consensus among local people on how *T. patula* escaped from home gardens was that the seeds moved into farmlands along with manure which is usually composed of wastes of home garden cleaning, ash and cattle dung. Then, the plant found its way from farmlands into grazing fields and finally reached semi-natural vegetation. None of the interviewed people could confirm that it was eaten by animals.

According to the local residents, *B. prestinaria* is locally important in the production of honey. It has a popular name of "*Adey Abeba*" in Amharic, "Adiyo" in Shinasha and "*Egile*" in Gumuz languages. During September and October, the landscape is completely dominated by *B. prestinaria* and the plant is, accordingly, the most important contributor to honey production. It is weeded from farmlands, but is otherwise left undisturbed by humans. *B. prestinaria* is grazed by domestic animals in areas where grasses are scarce.

Species association study

A total of 114 plant species, belonging to 38 families, were found in the 26 plots that were sampled to analyze plants associated with *T. Patula*. The families rich in this species were Poaceae (24 species), Asteraceae (14) and Fabaceae (10). Thirteen families were represented by 2 to 7 species while the remaining 22 families had one species.

The ordered two-way table from TWINSPAN (Table 1) shows the plant associations obtained from the analysis. The species on the top are more abundant on the left side of the primary division than on the right side. The species on the bottom are more abundant on the right side of the primary division than on the left side. The species in the middle are somewhat constant, occurring widely on both sides. TWINSPAN used two species, *Centella asiatica* (L.) Urban and *Asterolinon adoense* O. Kunze, as indicator species to demarcate the group of samples to the left of the primary division ("Association 1"). On the other hand *Bidens biternata* (Lour.) Merr. & Sherff. and *Rhynchosia nyasica* Bak. were used as indicator species for the right side of the primary division, "Association 2". The species in "Association 1" are mainly herbs, except *Ziziphus abyssinica* Hochst. ex A. Rich., which is shrubby. In "Association 2", three tree species *Acacia hecatophylla* Steud. ex Rich., *A. polyacantha* Willd. and *Ficus sycomorus* L. were found in addition to one shrubby species, *Flueggea virosa* (Willd.) Voigt. Weedy species are found in both associations; *Guizotia schimperi* Sch. Bip. ex Walp.– native species, and *Galinsoga quadriradiata* Ruiz & Pavon, – introduced and naturalized species, in "Association 1", and the grasses *Eleusine africana* Kenn. -O`Byrne, *Panicum atrosanguineum* A. Rich. and *Pennisetum polystachion* (L.) Schult., all native species, in "Association 2". Only two sample plots (24 and 25) were sampled from undisturbed natural vegetation and they were linked to "Association 2". Only one of the weeds (*G. quadriradiata*) was found in these sample plots. *Tagetes patula* was not found in these two sample plots.

Table 1. An ordered two-way classification from TWINSPAN showing the plants associated with *Tagetes patula*.

Species	Samples																						
				1							2	1	2	1	1	2	1	1	1	1	2	2	
	5	6	8	0	2	7	1	3	4	9	6	9	0	2	3	3	1	5	6	7	4	5	
Brachiaria brizantha	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	**Association 1**
Asterolinon adoense	1	2	2	1	2	2	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	
Centella asiatica	2	3	3	3	3	3	2	3	2	3	-	-	-	-	-	-	-	-	-	-	-	-	
Spermacoce chaetocephala	2	1	2	2	1	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	
Guizotia schimperi	3	3	3	2	3	3	-	3	3	3	-	-	-	1	-	-	-	-	-	-	-	-	
Paspalum scrobiculatum	2	2	-	1	2	1	-	1	1	1	-	-	-	2	-	-	-	-	-	-	-	-	
Sporobolus piliferus	3	2	2	2	1	1	-	1	1	-	-	2	-	-	-	-	-	2	-	-	-	-	
Chloris pycnothrix	2	-	1	2	-	-	-	-	-	-	-	2	-	-	-	-	1	-	3	-	-	-	
Eragrostis schweinfurthii	-	2	-	1	-	1	-	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	
Justicia ladanoides	-	1	1	-	1	1	1	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	
Commelina subulata	-	1	1	-	1	2	2	1	1	1	-	1	-	1	-	-	1	-	-	-	-	-	
Aneilema hirtum	-	-	1	-	1	1	2	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	
Ziziphus abyssinica	-	-	-	1	3	3	-	-	3	-	-	-	2	-	-	-	-	-	-	-	-	-	
Crotalaria ononoides	-	-	-	-	2	-	3	3	2	-	-	-	-	-	-	-	3	-	-	-	-	-	
Galinsoga quadriradiata	-	-	-	-	1	-	2	1	2	2	-	-	-	-	-	-	-	-	-	-	1	1	
Plectranthus sp.-Coll.1427	-	-	-	1	1	1	2	1	1	1	-	-	-	2	2	-	1	1	-	-	-	-	
Leucas martinicensis	-	1	1	1	-	1	2	1	2	-	1	-	-	1	-	-	1	1	2	-	-	-	
Brachiaria semiundulata	-	1	1	2	1	1	-	-	1	1	3	-	2	2	-	-	2	2	-	1	-	-	Constant Species
Digitaria ternata	2	2	2	1	1	1	1	2	1	1	-	2	2	3	-	-	1	3	1	-	-	-	
Trifolium rueppellianum	1	2	2	1	2	3	1	2	1	1	1	3	2	2	-	-	2	2	2	-	-	-	
Setaria pumila	1	-	1	1	1	-	1	1	1	1	2	3	2	1	-	1	2	1	2	1	-	-	
Bidens prestinaria	2	1	-	-	1	1	2	1	4	1	-	1	-	2	-	3	2	3	2	3	-	-	
Hygrophila auriculata	2	1	1	2	-	-	2	3	2	-	2	2	2	-	-	1	-	-	1	-	1	-	
Ageratum conyzoides	1	1	1	-	1	1	-	3	2	1	2	1	-	2	-	1	2	1	2	-	-	1	
Spermacoce sphaerostigma	1	2	2	-	2	2	1	1	2	1	3	-	1	2	2	1	1	1	1	-	1	1	
Phyllanthus pseudoniruri	1	1	-	1	2	1	1	1	2	2	-	-	1	1	-	-	1	1	1	1	-	1	
Panicum atrosanguineum	1	-	-	-	-	-	-	-	-	-	-	1	2	1	-	-	-	2	1	-	-	-	Association 2
Tagetes patula	-	-	-	-	1	3	2	2	2	-	3	1	2	3	3	3	3	3	3	3	-	-	
Acacia hecatophylla	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	
Oplismenus burmannii	-	-	-	-	-	-	2	-	-	-	-	2	3	-	3	2	-	-	-	-	3	3	
Eleusine africana	-	-	-	-	-	-	-	1	-	-	2	3	3	2	-	-	1	1	3	-	-	-	
Bidens biternata	-	-	-	-	-	-	-	-	1	-	2	1	1	2	2	2	2	2	2	2	2	1	
Polygala persicariifolia	-	-	-	-	-	-	-	-	1	-	-	1	1	1	1	1	-	-	-	2	1	1	
Pennisetum polystachion	-	-	-	-	-	-	-	-	-	-	3	-	2	2	1	2	2	-	2	-	-	-	
Flueggea virosa	-	-	-	-	-	-	-	-	-	-	2	-	2	3	3	2	3	-	-	-	3	3	
Rhynchosia nyasica	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	2	1	1	3	1	1	
Acacia polyacantha	-	-	-	-	-	-	-	-	-	-	-	1	-	3	1	3	2	2	3	3	-	-	
Ocimum trichodon	-	-	-	-	-	-	-	-	-	-	-	-	2	1	2	-	1	3	2	1	-	-	
Jasminum grandiflorum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3	-	3	-	-	
Ficus sycomorus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	3	3	
	Cluster 1										Cluster 2												

Note: Horizontal and vertical scales indicate the main divisions of the species and samples, respectively. Values indicate the scale of abundance, with absence of values represented by -.

Seed production

The propagule production and the average number of capitula per plot are given in Table 2. *B. prestinaria* has less florets in total per capitula (*ca.* 44) than *T. patula* (*ca.* 56). On the other hand, *B. prestinaria* has more flower heads per plot (*ca.* 10) than *T. patula* (*ca.* 4). Thus, *B. prestinaria* has over twice as many propagules per plot (*ca.* 455) compared to *T. patula* (*ca.* 225).

Table 2. Capitula and average propagules production in *T. patula* (n=100) and *B. prestinaria* (n=20), mean ± S.D.

Parameters	Tagetes patula	Bidens prestinaria
No. of capitula/plot (4 m²).	4.0 ± 4.6	10.4 ± 24.0
Average no. of propagules/capitula	56.2 ± 8.7	43.8 ± 7.8
Average no. of propagule/plot (4 m²).	*ca.* 225	*ca.* 455

Fire simulation experiment

T. patula has the longest (and also the lightest) propagules than *Z. elegans* and *B. prestinaria* (Table 3). *T. patula* seeds started germinating on the second day after heat treatment. The germination rate for propagules exposed to higher temperatures was slightly lower compared to the control. No germination was observed in the propagules treated at 120°C/5 minutes (Fig. 3). Mean total germination frequency in *T. patula* for all the treatments combined was 59% (± 17%).

Table 3. Characteristics of the propagules of the three study species (mean ± S.D., n =10 per species).

Plant species	Propagule length (mm)	Propagule weight (mg)
Tagetes patula	10.4± 0.6	1.9± 0.4
Zinnia elegans	6.3± 1.0	4.9± 0.8
Bidens prestinaria	6.0± 0.8	2.6 ± 2.4

Z. elegans had the heaviest propagules (Table 3) while seed germination started after the third day of heat treatment and continued for 91 days. Mean total germination frequency in *Z. elegans* for all the treatments was 81% (±13%), with highest germination frequency at the 120°C/1 minute treatment (98%). *Z. elegans* had the highest germination frequency in all treatments compared to the other species. The control treatment (78%) gave the lowest germination frequency except for the 120°C/5 minutes treatment (36%).

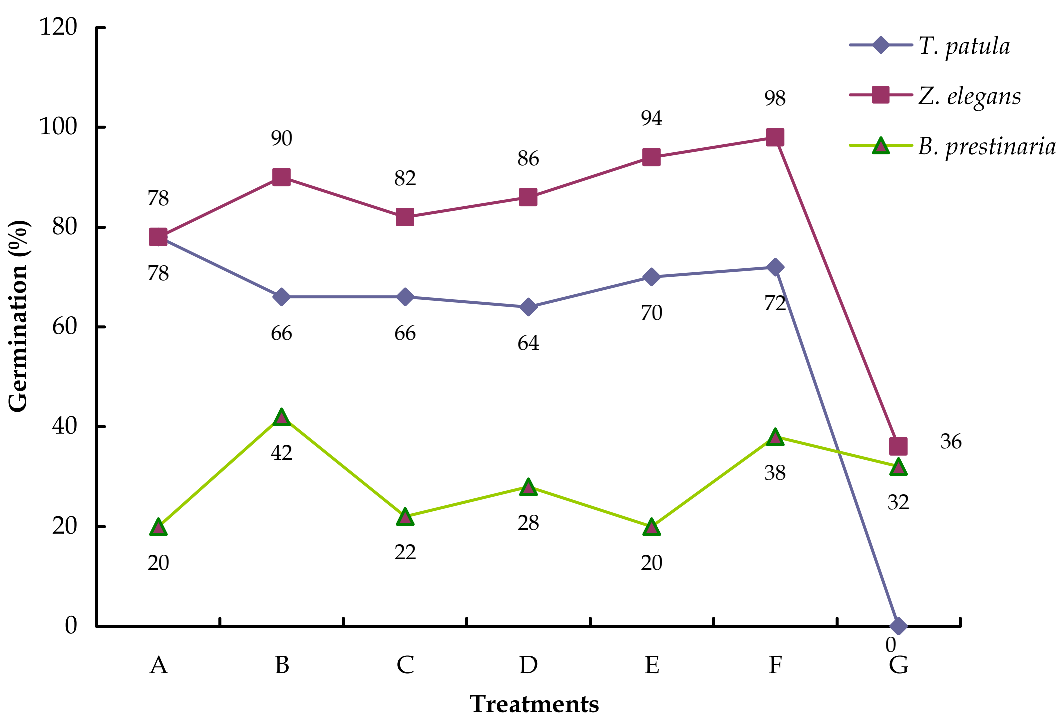

Fig. 3. Germination rate of the three species (*Tagetes patula*, *Zinnia elegans* and *Bidens prestinaria*) after exposure to different heat shock treatments. (A=control, B=60°C/1min, C=60°C/5 min, D=90°C/1min, E=90°C/5min, F= 20°C/1min, G=120°C/5min.).

B. prestinaria had the shortest propagule (Table 3) and started germinating on the seventh day after heat treatment. The last germination was registered 126 days after heat treatment started. Mean total germination frequency in *B. prestinaria* for all the treatments combined was 29% (±7%), which is the lowest frequency of the three species. *B. prestinaria* showed an increased germination frequency in the intermediate and higher heat treatments compared to the control (20%). The 60°C/1 minute treatment gave the highest germination frequency (42%).

One Way ANOVA was used to find if there were significant differences in germination frequency in the different temperature treatments. The total p-value between groups for *T. patula*, was 6.136E-11. There is, therefore, a significant difference between treatments at a confidence level of 95%. The p-value between groups for *Z. elegans* was 3.09E-7, also significant, whereas the p-value for *B. prestinaria* was 0.3381, thus not significant.

Soil seed bank

A total of 1204 seedlings belonging to 37 species were germinated from the soil samples. Of these, 800 were recorded from seed banks in "Site 1", 193 from seed banks in "Site 2", and 211 from seed banks in "Site 3". Both target species, *T. patula* and *B. prestinaria,* appeared in the seed bank; the former with a total of 10 seedlings (7 in "Site 1", and 3 in "Site 2"), and the latter with a total of 16 seedlings (14 in "Site 1", 1 in both "Site 2" and "Site 3"). Three different growth forms (grasses (7 species), herbs (27) and trees (3)) appeared in the seed bank and about 24 of the species were also recorded in the field while 13 species were represented in the soil seed bank only.

DISCUSSION

The escaped populations of *T. patula* were found over fairly large areas in Bulen, Dibatie and Mandura districts of BGNRS at altitudes ranging from *ca.* 1100 m to *ca.* 1900 m. Home garden plants are found at altitudes of up to 2300 m. *T. patula* was not observed as an escape at higher altitudes where low temperatures possibly restrict its competitive potential. In addition, there might be less available habitats at higher altitudes because of the higher density of people. Another reason for finding escapes only at lower altitudes might be due to their existence here for a longer period.

The species has been grown in home gardens in the area for more than 20 years. The Amharic name "*Yederg Arem/Derg weed" is* associated with the time of the Derg military rule (1974–1991), during which *T. patula* most likely escaped first and got established as a weed. Since 2001, the areas invaded by *T. patula* have been apparently increased. As a recently introduced plant and as an exotic colonizer, *T. patula*, might be in the slowly increasing phase of the sigmoid curve (lag phase), in which its impact is rather insignificant. The exponential part of the curve might not have been reached, but if/when such a phase is reached, the impact on other species might increase considerably.

In the species association analysis, *T. patula* was not found in undisturbed/pristine woodlands and was mainly found in abundance in "Association 2" which was characterized by trees and species that demand some shade and moisture (Edwards *et al.,* 1995, 1997; 2000; Hedberg and Edwards, 1989; Phillips, 1995; Hedberg *et al.,* 2003; 2006; Mesfin Tadesse, 2004). *T. patula* was less frequent in "Association 1" which, as judged from the species composition, represents open and drier habitat types. Both associations where *T. patula* occurs include weedy species, indicating that a certain amount of disturbance has taken place. Thus, *T. patula* prefers disturbed areas, but is rare in sun exposed and dry areas.

B. prestinaria was also found in both associations, and appears to be indifferent when it comes to conditions separating "Association 1" and "Association 2". Observations revealed that it often co-occurs with *T. patula* in open land-scapes, and in such situations *B. prestinaria* tends to dominate. In the situation of co-occurrence *B. prestinaria* might create the necessary shade regime for *T. patula*.

The ability to produce relatively high numbers of propagules in the absence of natural enemies might be among important factors that contributed to the apparent success of *T. patula* as invader in BGNRS. It has been suggested that the size of propagules represents a compromise between the requirement for dispersal, which would favour small propagules and the requirement for seedling establishment, which would favour large propagules (Hailu Shiferaw *et al.,* 2004). For plants like *T. patula*, occurring in more or less disturbed sites where open ground is created relatively frequently, a large number of small propagules might be more important than large propagules with elaborate dispersal mechanisms. The relatively small size of *T. patula* propagules facilitates burial because they might easily filter into cracks or small openings that often are created in disturbed soil.

Results from the fire simulation experiment revealed that 78% of *T. patula* seeds germinated from the control, while germination was lower for propagules treated with different dry heat treatments (except the highest temperature impact *i.e.*, 120°C/5 minutes in which there was no germination at all). The statistical analysis also revealed that only the higher temperature treatment has significant impact on the seeds of *T. patula.* This suggests that the propagules, to a certain degree will withstand heat, unless the heat becomes excessive.

Z. elegans showed a higher germination frequency than *T. patula* at all heat treatments. Even though some propagules treated at the highest temperature survived, the germination rate was significantly lower compared to the other treatments. This suggests that *Z. elegans* cypselas have higher heat resistance than *T. patula*. This might be related to the fact that *Z. elegans* has the thickest cypsela wall.

B. prestinaria was less affected by the different heat treatments, than the introduced species. The germination rate in both the control and the harshest treatment was higher than for *T. patula* and *Z. elegans.* Relatively elevated germination frequency at 60°C/1 minute treatment supports the findings of Menassie Gashaw and Michelsen (2002) where a brief exposure of propagules of some species in fire-prone areas to fire resulted in higher germination frequency. Being an indigenous species in fire-prone area, *B. prestinaria* might have adapted to natural fire regimes through evolution.

The soil seed bank sample areas were grouped into three: most *T. patula* seedlings germinated from soil banks from "Site 1"- the *T. patula* dominated woodland. Although *B. prestinaria* was not dominant in this site, many seeds germinated from the soil samples. This might be due to the fact that this species is widespread and has been in the area for about 20 years. Seedlings of both species were also observed in soil samples collected from "Site 2" - *T. patula* and *B. prestinaria* dominated hill and "Site 3" - *B. prestinaria* dominated field. The density of viable seeds recovered from soil samples collected at the study sites indicates that both *T. patula* and *B. prestinaria* accumulate seed reserves in the soil. Relatively small seeds are characteristic of species which have persistent seed banks in the soil (Thompson and Grime, 1979; Demel Teketay, 1998). These reserve seeds serve as one way of regeneration/invasion ensuring recruitment of seedlings in the event of disturbance. Studies conducted in Ethiopia have shown that many, particularly early successional plant species, possess numerous long-lived soil seed banks, which contribute to their perpetuation after disturbance (Demel Teketay, 1998, Hailu Shiferaw *et al.,* 2004). The longevity of the seeds of both species in the seed bank is, however, not known.

CONCLUSION

The introduced and escaped species, *T. patula* has several characters that might enhance its invasive ability and hence might be considered as a potential threat to grazing fields and natural landscapes in western Ethiopia. It produces a large number of relatively small propagules and has a seed bank. It is well known that most invasive plants turning weedy, share these characters. From the result of fire simulation experiment, however, it is possible to conclude that the annual fire occurring in the woodlands of western Ethiopia may not allow invasion by any species which is not adapted to fire, such as *T. patula* and *Z. elegans.* In the absence of annual fire or at least when the temperature is low, invasion of the woodland vegetation in BGNRS might be inevitable. If fire is intended to be used as a control method, temperatures/time regimes similar to the harshest experimental treatment (120°C/5 minutes) might be necessary to control invasion. Some other ways to control the invasion of *T. patula* include pulling up the plants or cutting the plants near the ground. All methods would have to be repeated over several years because of the soil seed banks which provide seeds for germination under favourable conditions. So far, *T. patula* has no impact on the daily life of the local people and many like it as an ornamental plant. Local residents are not aware of the potential invasiveness of the species. Agricultural development agents need to inform people about invasive species and their characters and what will happen if the growth of these species increases exponentially. When people become aware of such situation, it will be easier to propose possible management methods.

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