ESTIMATION OF ENVIRONMENTAL AND ECONOMIC COSTS ASSOCIATED WITH ENCROACHMENT OF WOODY INVASIVE SPECIES IN THE BORANA RANGELAND, SOUTHERN ETHIOPIA: USING PARTICIPATORY APPROACH

YENEAYEHU, F.[1,2] – YOU, Y.[2] – XU, X. W.[1] – WANG, Y. D.[1*]

[1]*National Engineering Technology Research Center for Desert-Oasis Ecological Construction, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, 818 South Beijing Road, Urumqi 830011, Xinjiang, China*

[2]*University of Chinese Academy of Sciences, Beijing 100049, China*

**Corresponding author*
e-mail: wangyd@ms.xjb.ac.cn

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Abstract. Currently, woody invasive species cause for environmental and economic impacts and effect on country gross domestic product. This is observed in Borana rangeland where several woody invasive species infestation happened. This paper aimed to estimate environmental and economic cost of woody invasive species focusing on its distribution and abundance using participatory survey approaches. This approach estimates an average cost for each species by a ratio of management costs, and the annually expenditures incurred by a variety of households. Twelve (12) dominating woody invasive species were recorded in Borana rangeland that are encroached major part of grazing area and Acacia species are the most dominant one. Annually, from each household an estimated total of $29.9 million or 1.1 billion Ethiopian birr economic cost was recorded due to encroachment of woody invasive species and annual economic cost per person was around $424 or 15,137 Ethiopian birr. Cost estimates are the highest for Acacia species (*Acacia drepanolobium*, *Acacia bussei* and *Acacia mellifera*) accounting for 66% of the total estimated economic cost, followed by *Capparis tomentosa*, which also adversely impacts on ecological services. Such economic cost assessment of woody invasive species used as a monetary basis for ranking the species based on their impact and take prioritizing management actions. Further, the cost estimate approach used in this study could help as a model for woody invasive species economic impact assessments in other part of the rangeland area.
Keywords: *vegetation composition, economic cost, damaging rate, bush infestation, management*

Introduction

In savanna grasslands worldwide, the encroachment of introduced invasive species become the most extensive cause for rangeland degradation (Holechek et al., 2005). Invasive alien species (IAS) affects both the living and non-living environment through disruptions of ecological (biotic and abiotic) conditions of the rangeland (Angassa, 2007; Benjamin, 2017). Environmental impacts caused by the encroachment of IAS significantly affect the human well-being (UNEP, 2016) and their interaction (WHO, 2015). In Ethiopia, the encroachment of IAS occurs mainly in the rangelands (Abule et al., 2007). Encroached rangelands are at risk mainly due to competition with native grass species that used for livestock grazing resulting in an imbalance of the grass to bush ratio, a decrease in biodiversity, a decrease in rangeland productivity and a decline in carrying capacity (Gemedo et al., 2006; Dougill et al., 2016). In Borana rangeland encroachment of woody invasive species (WIS) increased rapidly and showed 75% of increasing rate compared from 1990 with 2019 (Yeneayehu et al., 2020). A human-

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induced disturbance of rangeland leading to the increase of WIS encroachment is mismanagement of rangelands (overgrazing) (Bond and Midgley, 2012). Recently, there are more than 35 invasive plant species identified in Ethiopia (EBI, 2014). Introduced Acacia species, such as *Acacia drepanolobium*, *Acacia bussei* and *Acacia mellifera* and *Commiphora* species are the most dominant encroached WIS in Borana rangeland (Oba et al., 2000; Zinabu et al., 2020). In the most encroached rangeland area, up to 95% of the surface can be covered by those invasive species and caused suppressed growth of the native grasses and excludes livestock from ranging (Mitchard and Flintrop, 2013). This impact both environmental situation and livelihoods of both commercial and communal livestock ranchers (O'Connor et al., 2014).

The impact of WIS is more all-encompassing and has direct, indirect, and multi-dimensional effects that happen over varied times (Jones, 2016; Walsh et al., 2016), such as a drop in grass biomass production that leads to a decline in the rangeland's ability to support grazing (Espach, 2006). As a result, pastoralist income declines, and some causes result in significant economic and environmental losses throughout many regions of the nation (Ward, 2005; Angassa, 2014). Numerous scholars have significantly contributed to understanding the effects of WIS invasion on arid and semi-arid rangelands (Angassa, 2007, 2014; Abdella, 2010; Anteneh and Zewdu, 2016). It is difficult to estimate expenditures exactly because of WIS encroachment. This is due to the fact that in dry and semi-arid rangelands around the world, including Ethiopia, the precise advantage and disadvantage of each encroached WIS were not yet fully defined and classified (Siraj and Abdella, 2018). The majority of ecological and/or economic interventions in determining the effects of WIS invasion in rangelands should come before a thorough understanding of the causes of this phenomena (Ditomaso, 2000).

As a result, studies typically used proxies to illustrate the underlying economic effects of WIS encroachment, with a focus on native species whose damages from those WIS are challenging to measure (Pimentel et al., 2005). Other environmental and economic costs are also identified but cannot be quantified in Borana, particularly in Teltele rangeland. Management and rehabilitation costs are primarily directly observable costs related to practice like mitigation, exclusion, and adaptation practice taken by affected pastoralist found on the rangeland area (Oreska and Aldridge, 2011). Estimating environmental and economic impacts due to encroachment of WIS (*Fig. 1*) used to provide a standard information for cost-benefit analysis and for reasonable management and ecological policy (Oreska and Aldridge, 2011). Native grass species at Borana rangeland are at risk due to direct competition and other indirect impact of encroached WIS (Teshome et al., 2012).

However, there is a dearth of data on how much money WIS encroachment has cost the economy and how well the pastoral communities in the Borana rangeland are doing. Furthermore, the absence of empirical data on the effects of WIS encroachment restricts the availability of fundamental knowledge for cost-benefit analyses, the development of effective management strategies, and an overall comprehension of species characteristics and effects. In the study area, it is somewhat difficult to estimate and quantify the economic cost caused by WIS effects; nevertheless, information utilized to assess impacts on grazing rangeland, agriculture, livestock, and public health can be gathered from the local people and stakeholders. In this study we tried to develop a methodology for cost assessing of dominant encroached WIS over arid and semi-arid rangeland. The implication of this survey-based approach used to estimate the environmental and annual economic costs of arid and semi-arid rangelands because of

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those dominated species in Borana rangeland and used to address the knowledge gap outlined above. This study therefore aimed to answer the following questions: At what extent costs of encroachment of WIS on the native rangeland species and human wellbeing's in the study area? And how can issues of encroachment of WIS at rangeland be sustainably addressed? So, the objective of this research was to estimates of the environmental and annual economic costs associated with the encroachment of WIS that dominantly established, and recommend sustainable management techniques in Borana rangeland. The Borana rangeland site was selected because it is one of the most encroached area and the local communities in this area highly vulnerable to rangeland degradation and other impacts due to WIS compared with other areas found in Borana zone. In this estimated cost considering annual cost variation occurrence with respect to management action, infestation rate and environmental fluctuation difference will important. The relationship between reported annual economic cost of livelihood/year and management costs spent/year for commonly used management techniques by the local community is also investigated to recommend which measure better for WIS management from economic aspect.

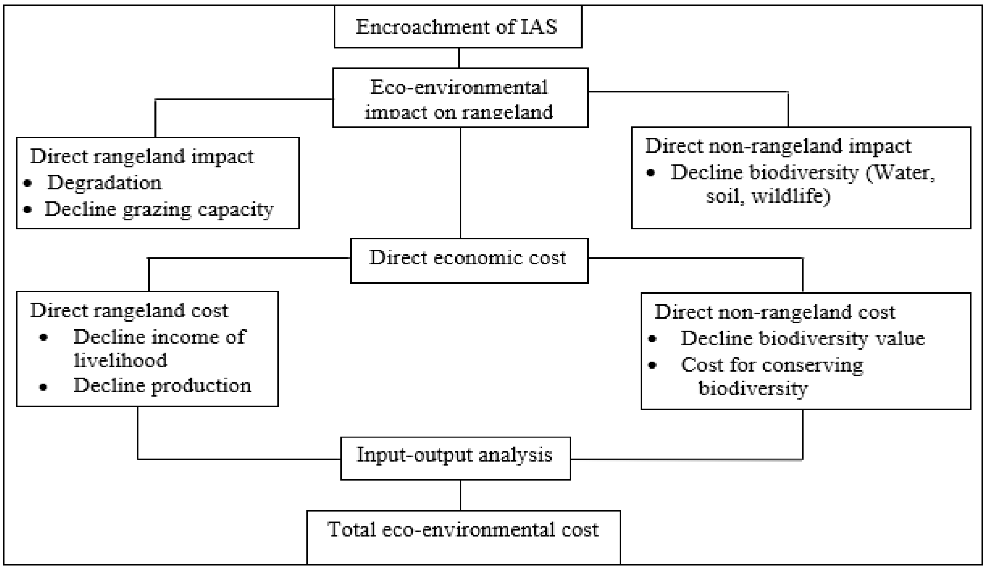

Figure 1. *Flow chart indicating economic and environmental impact of WIS encroachment in rangelands (modified from Lesoli et al., 2013)*

Materials and methods

Study area

The study was carried out in the Teltele district Borana zone, Southern, Ethiopia (*Fig. 2*) which covered an area of 15,430 km^2 of which 68% (10,492 km^2) is rangeland (Billi et al., 2015). It extends approximately between 4° 56' 23'"and 5° 49' 21" N latitude and 37° 41' 51" and 38° 39' 37" E longitude. The landscape is slightly undulating that ranges in altitude from 500-1500 m, having maximum of 2059 m (Coppock, 1994). The mean annual temperature varies from 28-33°C with little variation across seasons. The rainfall of the area is bimodal pattern, viz the main rain (Ganna) occurring from March-May which accounts 60% of the total rainfall occurring, and the small rain (Hagayya) which occurs in months from September-November that accounts 27% of the total rainfall

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occurring (Dalle et al., 2015). The dominant soil type of the rangeland comprises of 53% sand, 30% clay and 17% silt (Coppack, 1994). The vegetation mainly dominated by encroaching woody species, and those that frequently thinned out, include *Senegalia mellifera*, *Vachellia reficiens* and *Vachellia oerfota* (Coppock, 1994; Gemdeo et al., 2005). The 2017 national census data reported a total population of 100,501 in this district, 51,670 men and 48,831 women with 38,467 household. Cattle, goats, sheep, camels, mules, donkeys and horses are the main livestock species.

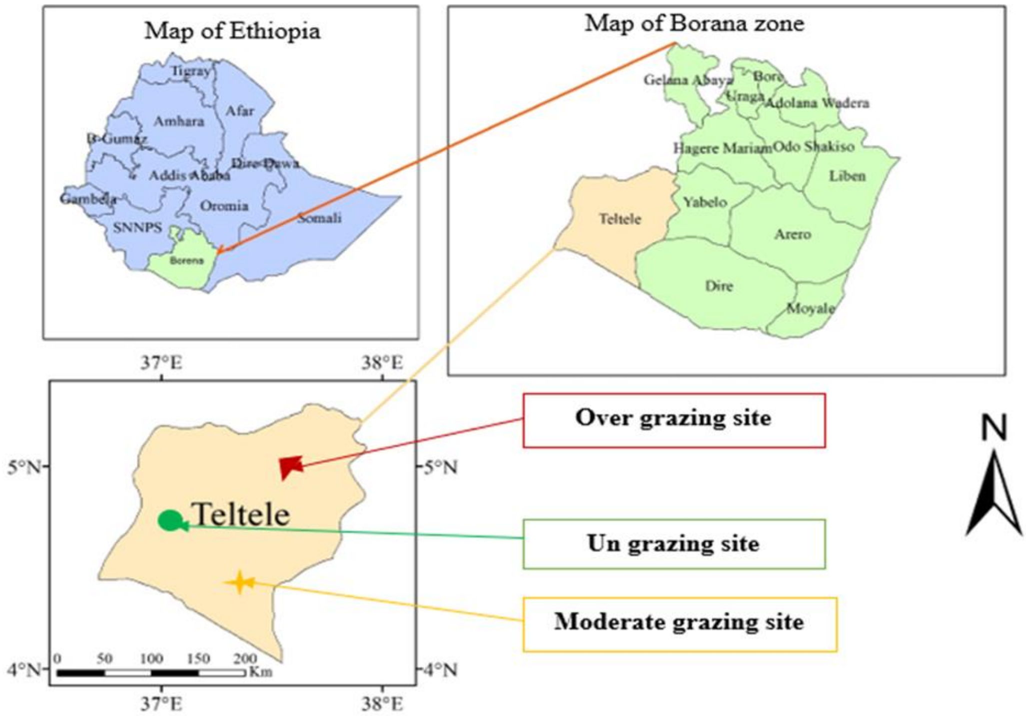

Figure 2. *Map of study site*

Methods

Socio-economic data

Respondent expert stakeholders and local community households were selected based on their direct connection to outputs from rangeland ecosystems and environments and settled on the rangeland area. And also, selection of respondents considered their familiarity with which woody species is native or invasive. The sample size of respondents was depending on the available time and budget for this project and we tried to took a representative sample from different sectors. A total of 210 individuals (140 males and 70 females) of them 152 local communities (LC). During respondent's selection from the local communities' knowledgeable informants were selected with the help of local administrators mainly elderly men, women, religious leaders and opinion makers in the community especially of the Abba Gada (Terefe, 2011). Additionally, 58 individuals involving during the interview data collection, 2 of them are agricultural experts (AE), 2 of them are livestock experts (LE), 2 of them are tourism experts (TE), 2 of them are natural resource experts (NRE), 10 of them are livestock traders (LT), 2 of them are wildlife experts (WE), 30 of them are local hotel

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and other livestock output related workers (HLW), 2 of them are environmentalists (EE), and 6 of them are from local non-governmental (NGO) origination worked on rangeland and livestock related issues were interviewed and provided information on impact WIS and dynamics of Borana rangeland. Then selected stakeholders were stratified based on stakeholder group and surveying within each group using structured questionnaires by face to face interview, mail questionnaires and continues phone interviews. Interviews were conducted by the help of trained experts, who had experience with conducting similar surveys and were fluent in the respective local languages with close follow-up of the principal investigator. Considering their educational level of the local communities, our questioners were focused on their experience observation and impacts based on their expectation, rather than scientific explanation. The questionnaire basically focused on about presence or absence of WIS, its abundance, environment and economic impacts associated with WIS, and management costs (for monitor, control, eradication and others). Furthermore, questionaries' also focused on assessing impacts on native grass species, productivities and estimation of the annual loss of livelihood economic cost/year. Economic values were converted from local currencies to ($) US dollar, using early 2020 exchange rates (1$ = 35.7 Ethiopian Birr (ETB).

Identification of dominant WIS in Borana rangeland

Both vegetation and socio-economic data were collected from the respondents in order to gather important information used to address the specific objectives of the study. Then, established a total of 108 sampling plots of 50*50 m systematically placed along three transect lines running parallel direction to collect vegetation type and associated variables both during the dry and rainy season in 2020. During WIS data collection we tried to consider grazing intensity's and sampling sites were from overgrazing site, un-grazing site, and moderately grazing sites (*Fig. 3*). The distance between transect lines was 3 km, while the distance between sample plots was 50 m. Then all WIS individuals within each sample plot were counted, and their species was recorded. Local names of species were recorded with the help of respondents. Based on the local names of species, corresponding scientific names were obtained with the aid of taxonomic publications (Bekele, 2007).

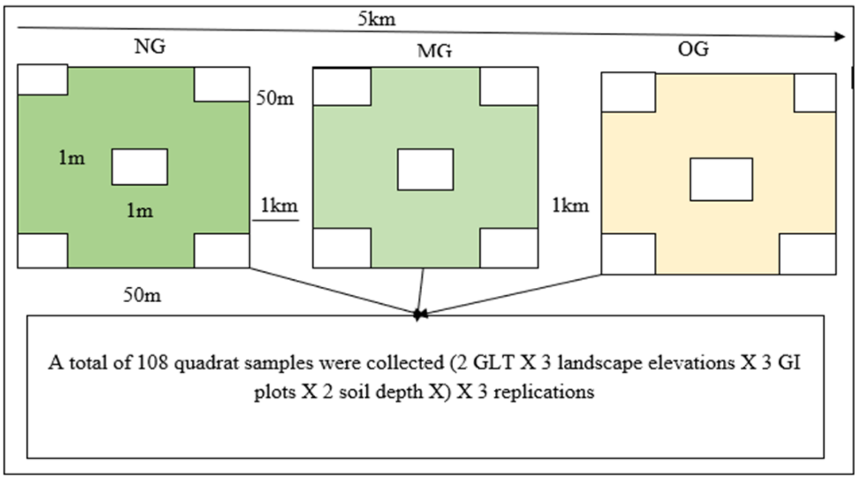

Figure 3. *Sampling plot layout. Note: GLT = grazing land type, GI = grazing intensity, NG = non- grazing site, MG = moderately grazing site, OG = over-grazing site*

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Estimation of environmental and economic costs of WIS in Borana rangeland

Information on environmental and economic cost resulted because of encroachment of WIS in Borana rangeland was gathered from respondent’s data and the annual economic cost of each species was estimated *Equation 1* and the sum of overall cost caused by all WIS was calculated using *Equation 2* modification of Oreska and Aldridge (2011) approach.

$$Y_i = R_i \times A_i \times E_i \quad \text{(Eq.1)}$$

where Y_i = represented yearly overall cost a species i, R_i = represented coverage of WIS of i, A_i = represented management related effort and cost for species i and E_i represented annual total economic cost of a species i at household level. And then the economic cost data were up scaled to the population level by changing the interviewed household responses (210) to the total household size (38,467) to calculate the total capital from the whole household in the study area. Then the sum of total overall economic cost of Borana rangeland associated with encroachment of WIS calculated as the sum of each species annual overall cost *Equation 2*. These total economic cost values were then averaged for each community to calculate economic cost per each individual level.

$$Tc = \sum_{n=1}^{n} \mathrm{Ti} \quad \text{(Eq.2)}$$

where Tc = represented the total economic cost associated with all WIS existed on the area, n = represented the total number of WIS (in our case n = 12), T_i = represented the total overall annual economic cost of a species i.

Statistical analysis

Data obtained through interviews and informal group discussions from the respondents were summarized and analyzed using a Statistical Package for Social Sciences (SPSS) version 15.0 for windows. We also used regression analysis to determine how environment and economic costs related with the abundance of WIS in the study area. The abundance (RA), Dominance (RD) and relative frequency (RF), was calculated as follows using *Equations 3, 4* and *5,* respectively (Terefe, 2011).

$$RA = \frac{\#\text{of individuals of species} \times 100}{\text{Total \# of individuals}} \quad \text{(Eq.3)}$$

$$RD = \frac{\text{Dominance of species} \times 100}{\text{Total dominance of all species}} \quad \text{(Eq.4)}$$

$$RF = \frac{\text{Frequency of species} \times 100}{\text{Frequency of all species}} \quad \text{(Eq.5)}$$

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Results and discussion

Socio-demographic characteristics of the respondents

The respondents' gender, occupation and level of education were some of the main demographic feature's that the authors considered for this study to remove the biased from our data (*Fig. 4*).

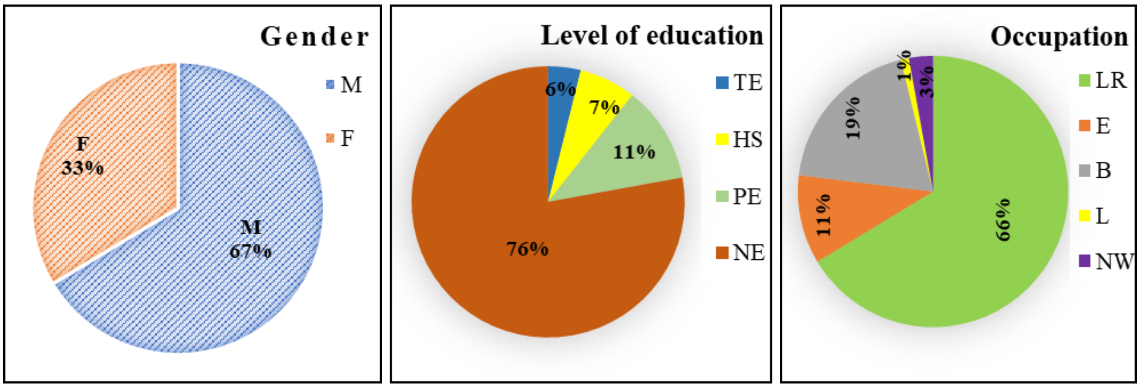

Figure 4. *Distributions of respondent's demographic characteristics. M = male, F = female, TE = tertiary education (college and university), HS = high school, PE = primary school, NE = not educated, LR = livestock rearing, E = employment, B = business, L = labor work, NW = Not known work*

Data collecting also took into account the participant's gender ratio. However, in the research area, the majority of family responsibilities outside the home including farming, raising livestock, and other activities are primarily seen as falling to men, while women are more focused on domestic duties like caring for children and preparing meals, among other things. As a result, male families tended to have more experience with and knowledge about rangeland status and the estimated cost of loss due to WIS encroachment. However, in order to assess how male and female pastoralists understood, perceived, and dealt with the impact of WIS, we made an effort to include and balance gender engagement during the data gathering process. A fundamental aspect of socioeconomic behavior is education, and the majority of pastoralists had only an elementary education. According to the information gathered from the respondents, this is due to the educational system still not being adequately utilized and adjusted, which prevents the community from enforcing access to the infrastructure inside the pastoral community. As a result, most of the livelihood community that depends on livestock occupation has been dispossessed, and this was the major factor that caused most of the pastoralist's source of income to depend on livestock rearing followed by running their own business beside it.

Vegetation composition of dominant WIS in Borana rangeland

Through informal discussion, interview, and field observation focused on its impact on native grass species, rangeland productivity, environmental, and economic of the local communities in the Borana rangeland, twelve (12) dominant WIS belonging to five families (*Table 1*) were identified. These findings were then confirmed with data maintained by the Ethiopian biodiversity institute access and benefit sharing directorate

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(Yibekal, 2012; EBI, 2014). And also, further survey was conducted from the local pastoralist’s, scientific publications, primary and secondary data and physical observations with regards to ecological and economic impacts associated with the selected WIS, like costs and possible benefits and control or eradication methods. Our data showed that *Acacia drepanolobium* was the most abundant, frequently recorded, dominance, and high coverage followed by *Acacia mellifera* and *Acacia bussei* respectively in the study area. Almost all respondents report that *Acacia drepanolobium* as the most encroached species covered almost 32% of the grazing site hectar^{-1} followed by *Acacia mellifera* and *Acacia bussei* and estimated the others species coverage like the data indicated in (*Table 1*).

Table 1. *List of identified dominant WIS in Borana rangeland*

Scientific name	Common names (orm)	Family name	RF (%)	RD (%)	RA (%)	% coverage ha^{-1}
Acacia bussei	Hallo	Fabaceae	16.8	20.3	10.4	15.0
Acacia drepanolobium	Fuleensa	Fabaceae	22.7	25.5	38.4	32.0
Acacia mellifera	Saphansa gurraacha	Fabaceae	19.8	23.1	15.9	22.0
Acacia oerfota	Waangaa	Fabaceae	8.8	6.1	8.9	6.0
Acacia nilotica	Burquqqee	Fabaceae	4.5	3.2	3.7	3.5
Acacia seyal	Waaccuu diimaa	Fabaceae	2.2	2.5	1.9	2.0
Acacia tortilis	Dhaddacha	Fabaceae	4.6	3.1	2.2	3.1
Balanites aegyptiaca	Baddana lu’oo	Balanitaceae	5.0	3.7	3.8	4.0
Balanites rotundifolia	Baddan Okolee	Balanitaceae	2.9	2.2	1.7	1.5
Chionothrix latifolia	Garbicha	Amaranthaceae	4.3	3.0	3.4	3.2
Capparis tomentosa	Hammeessa homacho	Cappararidaceae	5.8	4.4	7.6	5.2
Commiphora terebinthina	Angullee	Burseraceae	2.6	2.9	2.1	2.5
Total			**100**	**100**	**100**	**100**

RF = relative frequency, RD = relative dominance, RA = relative abundance, % cover hectar^{-1} = percentage of estimated coverage of individual species based on respondents’ data in a given hector, Orm = Afaan Oromo

Economic and environmental costs of WIS

Information provided about the environmental and economic costs of the WIS ranged from narrow to comprehensive. This study incorporates the results obtained from the Borana rangeland community and stakeholders, using 210 respondents as a representative sample from different sectors. WIS infest almost all rangeland areas, and 87% of respondents reported the presence of all WIS in Borana Rangeland. All respondents reported the occurrence of *Acacia bussei*, *Acacia drepanolobium,* and *Capparis tomentosa* species, and these species are most likely to affect the environment and economy of the household (*Table 2*).

Economic costs

In the Borana rangeland, it is currently difficult to estimate the economic costs of WIS. This is typically caused by a lack of quantitative data on the effects on ecosystems and difficulties estimating nonmarket costs, such as those to society and the environment. Most respondents said that the management costs (such as those for control, monitoring, or eradication expenditures) and economic costs at the household level were anticipated to be between \$100 and \$500 per year, with > \$500 being the

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next highest estimate. Where they exist, certain species like *Acacia bussei*, *Acacia drepanolobiu,* and *Acacia oerfota* are more likely to have a high cost, whereas *Acacia tortilis*, *Balanites rotundifolia*, and *Acacia seyal* have a lower economic cost, both at household income and controlled expense cost based. According to the respondents' data, damaging rates were mostly reported as medium, followed by high, both economically and environmentally. The reported damaging rate was in line with the reported economic cost amount, i.e., the damaging rate for which a large number of respondents provided data was also much more closely related to the economic cost data (*Table 2*). However, few respondents reported because they did not know how much WIS affected their livelihoods in terms of economic, rangeland productivity, and environmental factors (*Table 2*). The estimation of associated costs by WIS varies based on the understanding level of respondents from different sectors (*Fig. 5*) and species (*Table 2*). Almost all of the LE, LT, HLW, EE, and NGO experts reported the cost of WIS was high (>$500), whereas AE, LC, and WE reported the cost of WIS was not high ($100-500)/year. This was because both AE and WE indicated that those WIS also have advantages behind their cost like conservation of soil erosion, habitat for wildlife, and others, so they have no significant cost, rather compensable value. In addition, the LC indicated that those WIS were used for charcoal production and used as a source of income, firewood, housebuilding material, and also as a shade for both their livestock and themselves during the dry season when the sun was strong. In general, there was a significant variation on the data recorded related to the economic cost vale of WIS associated with members of the local communities and other experts. This is basically because of the understanding level variation and also their working sector variation made them have different understanding level between them.

Table 2. *Respondents survey data on the estimated economic and management costs range and damaging rate of each WIS*

List of WIS	# Listed RIS (%)	# Economic costs at household level year $^{-1}$ (%)			# Management costs household^{-1}year $^{-1}$ (%)			# Damaging rate			
		< 100$	100-500$	> 500$	< 100$	100-500$	> 500$	NA	L	M	H
Acacia bussei	100	5	71	23	24	62	13	2	10	15	73
Acacia drepanolobium	100	2	65	33	18	57	25	-	4	8	88
Acacia mellifera	95	7	78	12	31	57	9	6	10	36	48
Acacia oerfota	96	6	67	27	33	52	15	1	20	41	38
Acacia nilotica	83	9	80	9	11	63	24	4	12	49	35
Acacia seyal	76	6	87	7	20	72	8	-	11	62	27
Acacia tortilis	62	14	80	3	37	52	8	7	22	57	14
Balanites aegyptiaca	90	5	84	11	11	66	23	-	20	58	22
Balanites rotundifolia	69	12	73	13	34	51	13	5	17	52	26
Chionothrix latifolia	88	3	91	6	17	51	32	-	16	54	30
Capparis tomentosa	100	4	86	10	7	76	17	-	14	62	24
Commiphora terebinthina	79	9	78	13	16	72	12	2	21	63	14
Mean value	**87**	**7**	**78**	**14**	**22**	**61**	**17**	**2**	**15**	**46**	**37**

= number of respondents reporting, NA = they do not have information, L = low, M = medium, H = high, $ = US dollar

Estimating total economic costs of WIS in Borana rangeland

Based on the information provided by respondents about each WIS estimated coverage, estimated economic and management costs, the total economic cost

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associated with each species and the total number of species/year in Borana rangeland were calculated using *Equations 1* and *2*. The range of estimated costs varies by species (*Fig. 6*) and relates to its area coverage, household level economic cost, and management effort cost. Both the direct and indirect economic costs of the dominant Acacia species (*Acacia drepanolobium*, *Acacia bussei* and *Acacia mellifera*) are accounts 66% of the total estimated economic cost, followed by *Capparis tomentosa*. *Balanites rotundifolia* species reported less economic cost as compared with all other existing encroached WIS (*Fig. 6*). The overall estimated economic cost of the twelve (12) encroached WIS in Borana rangeland based on the data obtained only from the respondents of household amounts to $163,000 or 5.8 million ETB/year *Equation 2* but could be higher through interaction with other factors. The comprehensive economic cost analyses have been estimated based on the total household number directly rely on the rangeland. So that from each household an estimated $29.9 million or 1.1 billion ETB annual economic losses was recorded from Borana rangeland due to encroachment of WIS.

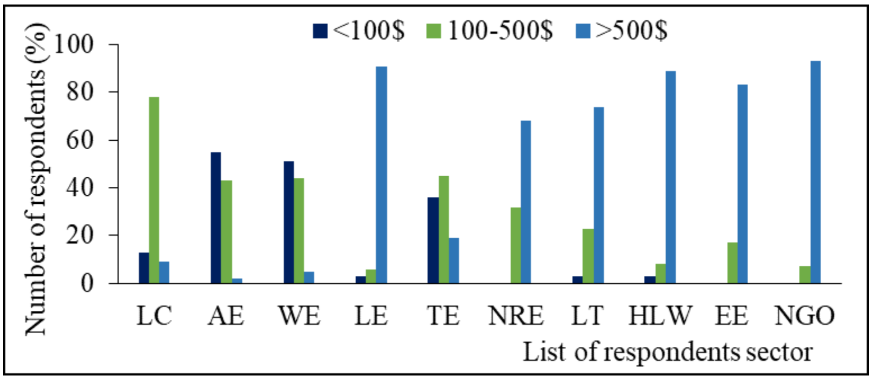

***Figure 5.** The percentage of respondent's data associated with cost of WIS with respective to each sector. LC = local comminutes, AE = agricultural experts, LE = livestock experts, TE = tourism experts, NRE = natural resource experts, LT = livestock trader, HLW = hotel and livestock related worker, EE = environmental experts, NGO = local non-governmental organization, $ = US dollar*

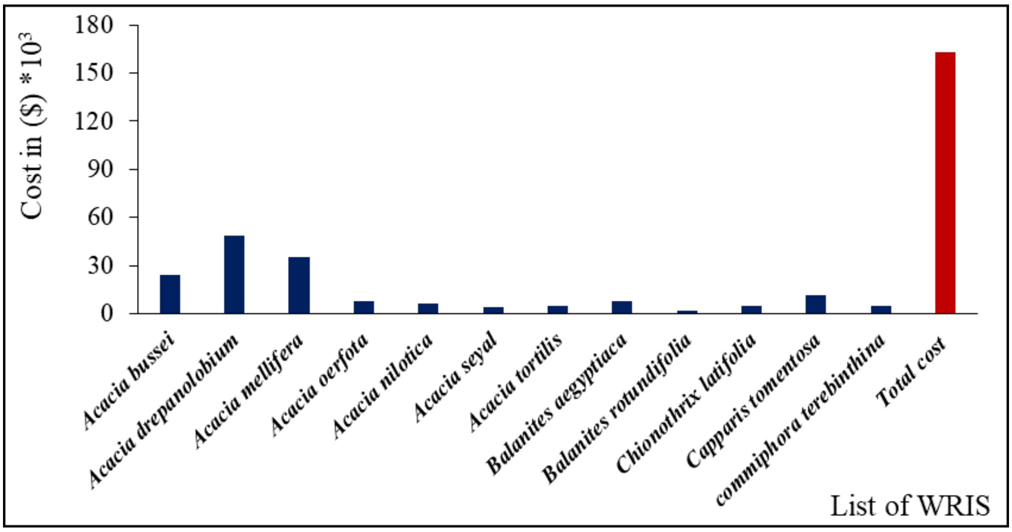

***Figure 6.** Reported annual economic cost of encroached WIS at Borana rangeland*

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And the total annual economic cost per individual was around $424 or 15,137 ETB. According to 2018 World bank Group report in Ethiopia a per capital income was less than $790 and this grouped under the category of poorest country. From this data we can easily estimate that one of the major factor that caused for lower income/year is rapid encroachment of WIS, means that if the cost per individual level that lost due to impact of invasive species ($424) was added per individual capital income ($790 + $424 = $1214) this will shift the country to middle income country level.

Environmental impacts

For environmental costs data, quantitative information was limited and suggested to use qualitative data based on respondent's report (*Table 3*). Among WIS, *Acacia bussei, Acacia drepanolobium, Acacia mellifera, Acacia oerfota, Balanites aegyptiaca* and *Balanites rotundifolia* are the most impacting species reported by more than half (50%) of the respondents. The most threating species is *Acacia mellifera* followed by *Acacia bussei* and *Acacia drepanolobium.* The primary unique features of *Acacia mellifera* among others it is highly poisoning of both livestock and human than others. Grass forage productivity, grass species richness/diversity, threatened on native grass species, livestock number and productivity, nutrient composition and soil moisture are the major affected features observed in Borana rangeland due to encroachment of WIS. Almost all respondents agreed that the decline of both number and productivity of livestock.

Table 3. *Respondents survey data (%) on environmental impacts of WIS in Borana rangeland*

Environmental impacts on	List of WIS											
	Ab	*Ad*	*Am*	*Ao*	*An*	*As*	*At*	*Ba*	*Br*	*Cl*	*Ct*	*Cot*
Grass forage productivity	93	95	91	78	65	80	72	79	81	82	91	73
Grass species richness/diversity	88	94	89	87	71	76	75	83	69	72	79	65
Native grass species	94	98	86	84	76	69	66	77	89	79	80	69
Livestock number and productivity	100	100	95	88	84	89	77	86	84	75	87	81
Poisoning of livestock	12	22	78	18	29	14	6	29	22	12	5	24
Soil properties	24	47	56	60	14	44	19	31	29	35	44	36
Nutrient composition	68	77	67	56	44	38	26	64	59	46	64	21
Soil moisture	71	34	61	33	18	48	31	39	37	31	22	54
Soil erosion	29	17	36	29	22	27	28	33	48	3	19	27
Human health	8	19	45	16	21	8	4	52	13	7	2	16
Average impact value (%)	**59**	**60**	**70**	**55**	**44**	**49**	**40**	**57**	**53**	**44**	**49**	**47**

Ab = Acacia bussei, Ad = Acacia drepanolobium, Am = Acacia mellifera, Ao = Acacia oerfota, An = Acacia nilotica. As = Acacia seyal, At = Acacia tortilis, Ba = Balanites aegyptiaca, Br = Balanites rotundifolia, Cl = Chionothrix latifolia, Ct = Capparis tomentosa, Cot = Commiphora terebinthi

Relationship between costs and WIS cover

Woody invasive species cover per hectare was positively and linearly related to annual economic costs from Borana rangeland area (*Fig. 7*), $R^2 = 0.93$ according to the respondents' data. The linear correlation analysis revealed that the level of impacts and overall costs on rangeland area primary depends on the abundance and encroachment status of WIS.

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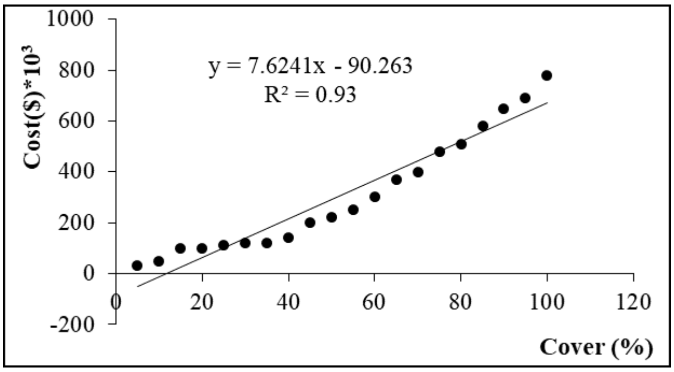

Figure 7. *The relationship between the economic costs and WIS cover per hectare*

Costs and the dimensions of contentious issues of WIS

The available information on economic cost of WIS in Borana rangeland is too fragmentary to determine an overall estimate of costs in quantitative figure, as is also occurred in other world rangeland area such as Canada (Leroy et al., 2022), USA (Pimentel et al., 2000). Associated impacts and costs of woody invasive species are strongly influenced by invasion abundance (Shackleton et al., 2007). When their abundance increases, associated costs increase and benefits decrease because of issues like resource accessibility (Wise et al., 2012). In Borana rangeland, Acacia species was initially considered as useful, but over time the negative impact became more apparent, causing to increasingly negative perceptions of the species (Tamrat and Stein, 2015). A similar situation occurred in other countries including Kenya, Sudan, South Africa, Australia Eritrea, Malawi and Pakistan (Maundu et al., 2009). The net economic benefits of WIS decrease as invasion densities increase in Teltele rangeland. According to Tilahun et al. (2017) report the net cost of having WIS in the rangeland area will become negative in 4-20 years depending on future rates of encroachment. A framework by Naseeruddin et al. (2013) also illustrate that WIS initially have high values, however as encroachment densities increase, costs become increase which caused to an increase of vulnerability for pastoral communities. This is due to the detrimental effects emerge, reached unmanageable levels and encroached the entire part of grazing land. Since, timely and effective management action was not implemented, infestation of WIS become out of control.

In some cases, there has been conflicts of interest occurred within the pastoral communities regarding selecting of management techniques to be to implemented, how best to conserve, use and even increase benefits while reducing negative impacts WIS in Borana rangeland (Siraj and Abdella, 2018). Not only in Borana rangeland, but also many parts of Ethiopia, encroachment of WIS are become a leading cause for the potential loss of land rights for local livestock herders, and violent conflict over limited natural resources between neighboring communities (Teshome et al., 2012). WIS are estimated to cause a loss of US$2 million per annum to the livestock industry in Ethiopia (Siraj and Abdella, 2018), $200-300 in the USA (DeLoach, 1984), $35.5 million in South Africa costs per annum (van Wilgen et al., 2012). The cost estimation process assessed in the current study has broad possible implications outside Borana. Very little is known about WIS costs, within the communities outside Borana in most part of Ethiopia, and in other African counties (Maundu et al., 2009). A stakeholder survey would be especially significantly important in these rangelands as a first attempt to document the magnitude of WIS costs. In such areas where significant work already exists, the process could be used

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to assess existing cost estimates, like those produced for the rangeland site (Wise et al., 2012). It is also important to reiterate that WIS environmental and economic costs underestimate lost total economic value because of lack of quantitative data on ecological impacts. The general cost-benefit trend of WIS in the rangeland area are summarized as follows used respondent's data as a baseline (*Fig. 8)*.

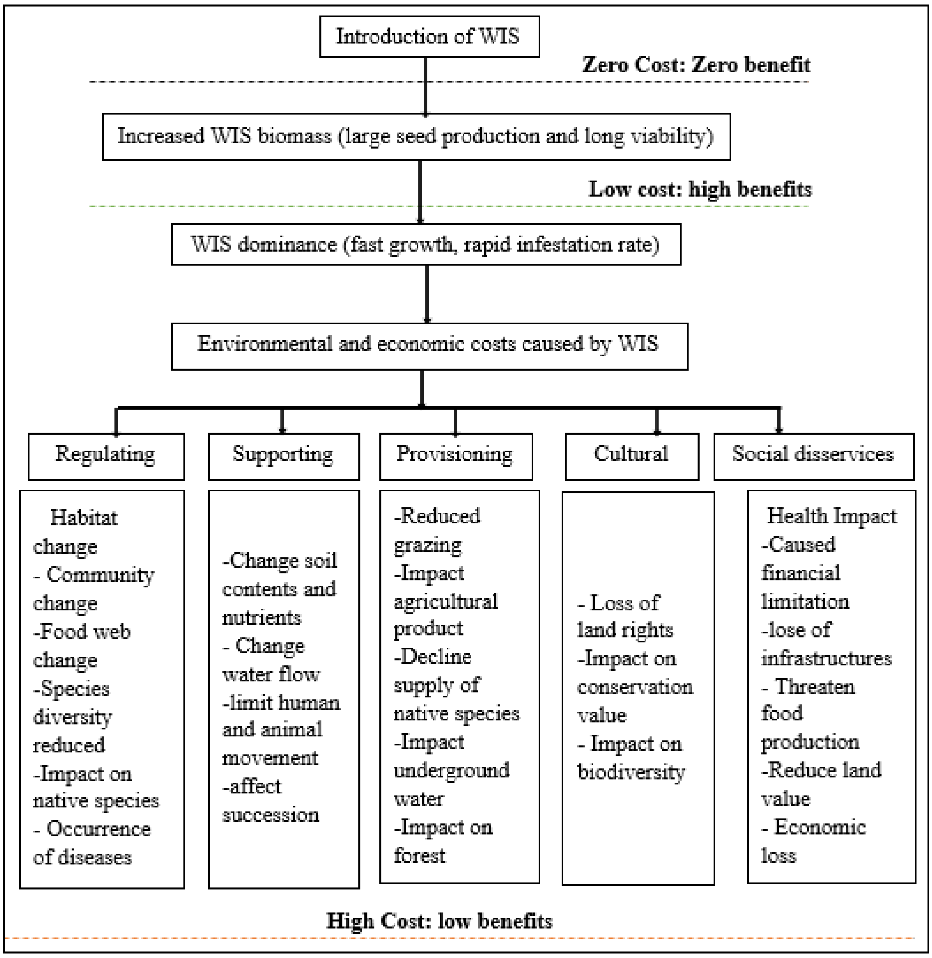

***Figure 8**. Cost and effect network diagram showing the impact of WIS in Borana rangeland*

During estimation of management costs used as proxies' techniques, since certain damage costs, lost option values, and lost non-use values are often non-uniformly distributed and difficult for stakeholders to estimate (Ndhlovu et al., 2011). The ecological impacts of WIS includes effects on survival, density, genetic integrity of native species, competition, succession, nutrient and water cycling on the rangeland area and estimated of cost with qualitative data is challenged (Richardson and Rejmanek, 2011). Some ecological impacts are represented in the generated cost estimates, but more ecological effects cannot be monetized, as a result ecosystem services might better estimate overall WIS impacts in the study area (Daisie, 2009). But using the participatory survey approach captures perceived costs, which factor highly in community sentiment toward WIS. However, these cost perceptions cannot include ecological considerations if the stakeholders have not awareness about WIS ecosystem alterations (Cusack et al., 2009). Finally, there are a big variation of confounding values

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related to differences in area size, the abundance of WIS, the seasonal variabilities of WIS to control, and subtle differences in operations between areas makes difficult to exact estimation but likely affect the data.

Research and management needs

In this section highlights future management and research issues that need to be addressed for sustainable WIS control and the limitations that currently constrain progress in the areas. Developing strategies from national to district and village level, in order to provide guidelines for further research and management in a targeted WIS encroached rangeland area is unique requirements in each country including Ethiopia (Witt, 2010). But still majority of the countries which infested by the encroachment of WIS do not have strategic plans for WIS management. Such national strategies and plans are used to set up frameworks on how to guide WIS management and research. There is also a need to create country specific strategic plans based on the types, invasion rates and impact situations of WIS within that specific country (van Wilgen and Richardson, 2014). Early identification and rapid response are a cost-effective way of managing WIS from getting out of hand and become encroached and causing for irreversible impacts in the future. There is also continuous follow-up and monitor the effectiveness of control techniques is highly needed in collaboration both in rangeland managers and researchers (Cusack et al., 2009). Some basic issues that need to be considered for research and management are described under (*Fig. 9*).

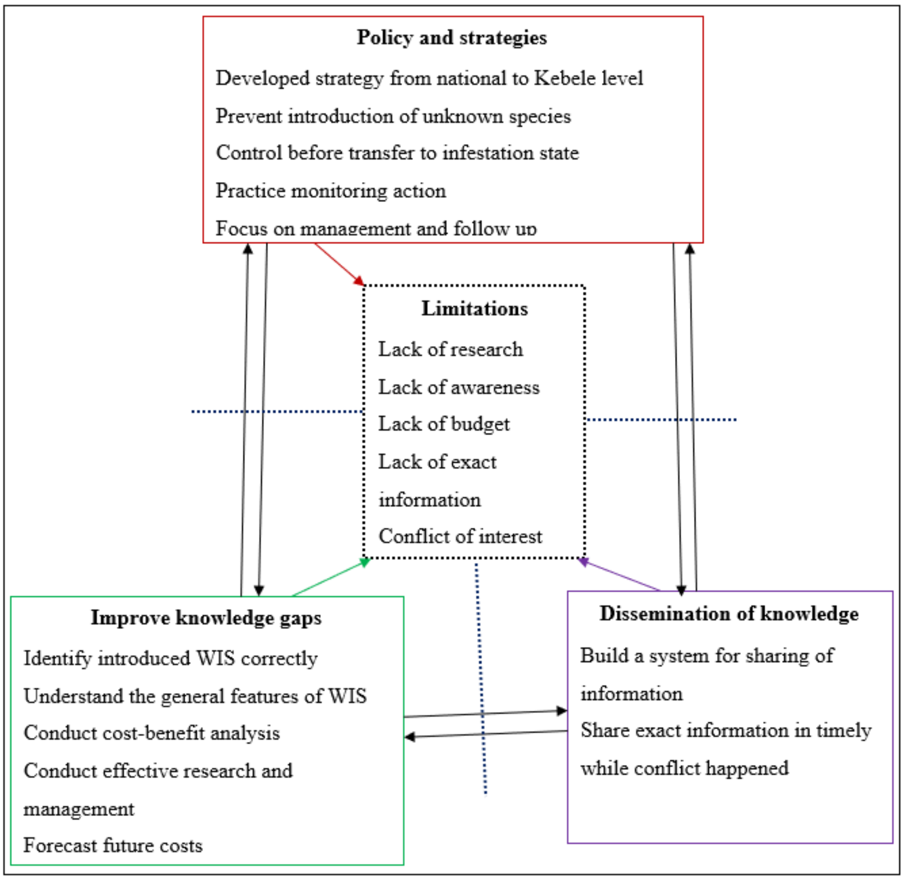

Figure 9. *Basic issues that need priorities during research and management conducted in Borana rangeland*

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In general, the results of this study can assist rangeland managers, particularly regarding the management of WIS at the study site. In addition to directing management focus, participatory survey-based cost estimates can justify control expenditures. The cost estimation process applied in the current study also has potential use at the microeconomic level (Kazmi et al., 2009). Estimating average unit costs for individual WIS could be important for both local communities and rangeland managers in identifying the best methods for their own management efforts.

Conclusion

The environmental impacts that can be identified and their direct linkage with economic costs will likely remain a facet of WIS impact assessments. The cost estimation approach applied in this study was used to develop conservative and more applicable methods for future WIS environmental and economic cost studies by managing for inconsistencies in economic cost estimation. The cost estimation concerns are conducted using direct stakeholder surveying, and double estimation concerns can be reduced by focusing on sustainable management expenditures. Using the cost estimation method applied herein, pastoral communities and stakeholders can better clarify their concerns using both direct comparisons between annual income and the ordering of WIS economic costs. Economic costs associated with WIS management were estimated, as were other impacts specifically pertaining to environmental costs. Economic costs that underestimate the cost value are also evaluated with the cost perception technique for contingent valuation. An assessment of economic cost from an ecosystem service aspect was used to verify the estimated economic cost reported here in the Borana rangeland WIS. However, the estimated cost generated by this study suggests that the problems associated with WIS in Borana rangeland, particularly for Acacia species and Capparis tomentosa, will have a significant impact. However, there is still a lack of ecological impacts and economic cost data for those species in Borana rangeland. Basically, the economic impact of forage yield and quantity loss caused by WIS in rangeland have not been well studied. This would address using quadrant sampling and grazing utilization studies in infested grazing areas, and nutritional analysis, palatability, and toxicity data are also needed. Further, there are also critical gaps within the local communities and stakeholders regarding its ecological features, effects, and the way to change it to maximize benefits and minimize costs, and management strategies. As a result, future action will consist of focused research and strategic planning that will aid in improving management, lowering costs, and increasing benefit flows.

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Competing interests. The authors declare that they have no conflict of interests.

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