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ETHIOPIAN JOURNAL OF BIODIVERSITY

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FLORISTIC COMPOSITION, DIVERSITY AND STRUCTURE OF SIX FOREST PATCHES, NORTHWEST ETHIOPIA

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ABSTRACT: The study was undertaken with the general objective of investigating the composition, diversity and structure of six forest patches in northwestern Ethiopia. Vegetation data were collected from 154 sampling plots of each 400 m^2 (20 m × 20 m). Species frequency, density, basal area, dominance, importance value index and population structure of the forest patches were analyzed using descriptive statistical tools. Floristic diversity and evenness were computed using Shannon diversity and evenness indices, respectively. The variations of floristic richness, density and basal area among the forest patches was tested using One-Way ANOVA in PAST software Package. The results of the study revealed that the study area harbored 212 species (122 woody and 90 herbaceous) belonging to 169 genera and 79 families. The Shannon diversity index and evenness values of the study area were 3.7 and 0.8, respectively. The highest number of species were recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiki, Kidamaja and Degera forests. The density, basal area and dominance of woody species were 2172.1 stems ha^{-1}, 41.2 m^2 ha^{-1} and 23.1 m^2 ha^{-1}, respectively. There were no significant variations of floristic richness, density and basal area among the forest patches. A number of tree species showed unhealthy population structure and were found to be at conservation risk. To reverse these changes, among other measures, undertaking restoration activities using locally threatened woody species is highly recommended.

Keywords: Basal area, Density, Diversity index, Importance value index, Population.

INTRODUCTION

The Ethiopian highlands particularly the Afromontane forests are among the mixed mountain and highland systems with complex zonation and they are part of the 29 biogeographic provinces of the Ethiopian/Afrotropical region of endemism (Brown and Lomolino, 1998). Moreover, the Afromontane vegetation of Ethiopia is part of the Eastern Afromontane hotspot that comprises high species richness and endemism (Friis, 1992, 2009; Friis et al., 2010). The distribution and richness of plant taxa is highly variable

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in Ethiopia. The general trend of species richness is that the southwestern, southern and southeastern parts of Ethiopia have the highest plant species richness, even though the values found for richness in some areas reflect high collecting intensity of samples (Friis, 2009).

The size and quality of remnant forest patches of Ethiopia particularly the study area is deteriorating at an alarming rate due to various threats (Berhanu et al., 2019). Those forests which are surrounded by hostile matrices such as agricultural and grazing lands and settlement are in most cases influenced by various factors such as fragmentation, disturbance and selective logging, which lead to gradual loss of key species; the process termed more suitably as "ecological decay" (Laurance et al., 2002). Fragmentation, by breaking down continuous landscapes into smaller, isolated patches, exposes forest edges to increased windthrow and light penetration. This can lead to reduced tree density at forest edges, as documented by studies like that of Chen et al. (2009) who reported a 20% decrease in tree density within 100 meters of the edge compared to the forest interior. Disturbances, encompassing events like wildfires and invasive species infestations, further disrupt established communities by creating canopy gaps and altering resource availability (Lindenmayer and Fischer, 2011). This triggers successional changes, often favouring fast-growing, light-demanding species over shade-tolerant ones, resulting in shifts in size distribution and potentially decreasing basal area due to the presence of smaller trees (Asner et al., 2014). Selective logging, while targeting specific high-value trees, creates lasting impacts even beyond the immediate removal. Gaps in the canopy trigger regeneration of shade-intolerant species, ultimately leading to a decline in canopy height and basal area dominated by smaller trees compared to undisturbed forests (Slik et al., 2015). Additionally, logging activities themselves cause physical damage to remaining trees and understory vegetation, further contributing to structural alterations (Brockerhoff et al., 2017). Collectively, these factors exert a complex influence on forest structure, often leading to decreased tree density, reduced basal area, and shifts in size distribution towards smaller trees, creating a less diverse and potentially less resilient ecosystem (Laurance and Williamson, 2001).

The forests of northwestern Ethiopia have not been investigated except few studies that were carried out on the temporal vegetation cover dynamics and vegetation distribution modelling (Berhanu et al., 2018; 2019), genetics of a single species – *Prunus africana* (Yineger et al., 2014) and floristic study of single forest fragment – Zengena Forest (Tadele et al., 2013) and Kuandisha forest (Berhanu et al., 2017).

Thus, we hypothesized that species richness, density and basal area of the six forest patches are different despite their inclusion in the "same vegetation type"; and a number of plant species in the study area are at conservation risk. The research objectives were to investigate; (1) woody species richness and diversity of forest patches; (2) structure of the forest patches and selected woody species; and (3) importance value index of selected woody species for conservation and management interventions.

MATERIALS AND METHODS

Study area

The study was conducted in forest patches of Guangua-Illala and Kahtasa forests, northwestern Ethiopia (Figure 1). It is located in the Gojam Floristic Region, western Ethiopian highlands (Friis et al., 2010), within a newly described vegetation type, namely Intermediate evergreen Afromontane Forest (Berhanu et al., 2018).

After a reconnaissance survey, six forest patches were selected and their altitude and grid references were noted. The forest patches are located between latitudes 10º47' N to 11º02' N and longitudes 36º32' E to 36º48' E. The altitudinal range lies between 1830 and 2660 m asl. The total area of forest patches is 2,920 ha, sizes ranging from 327 to 651 ha (Table 1).

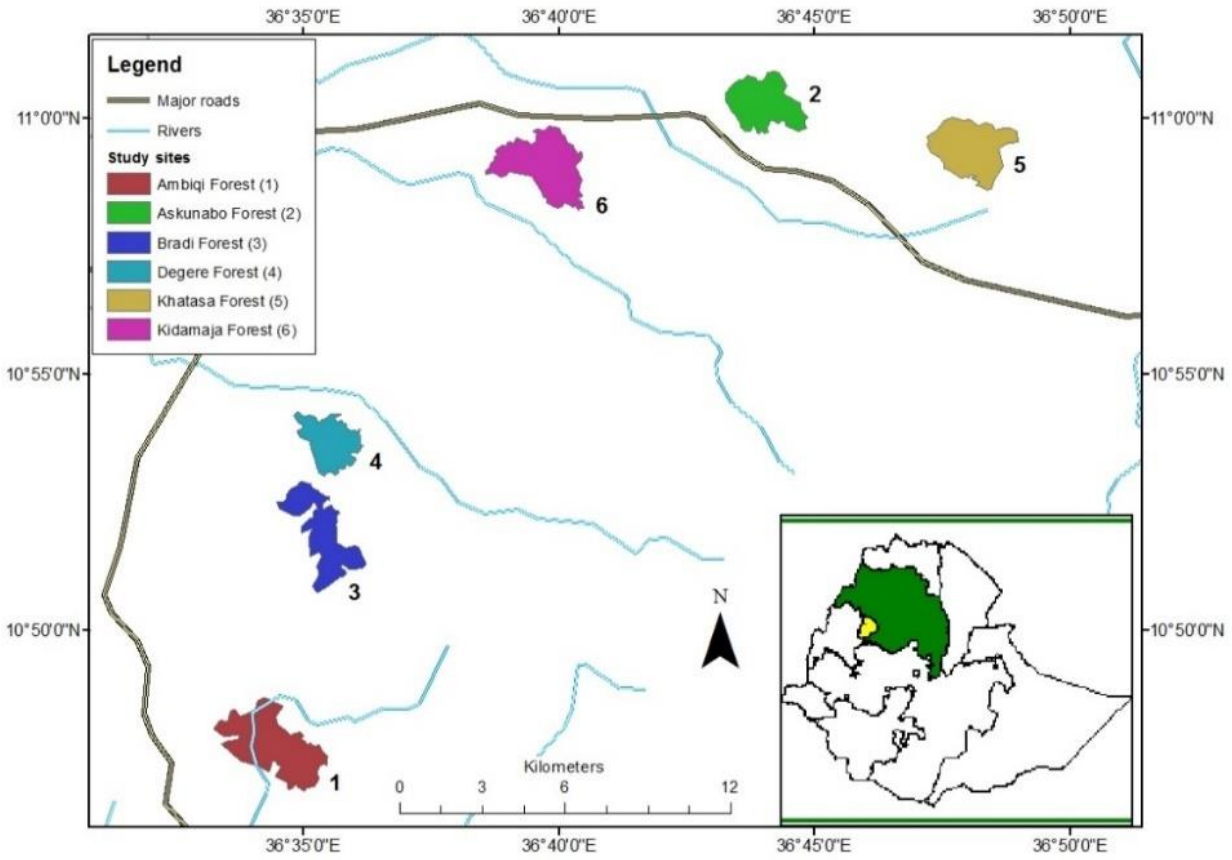


Figure 1. Map of studied forest patches in northwestern Ethiopia.

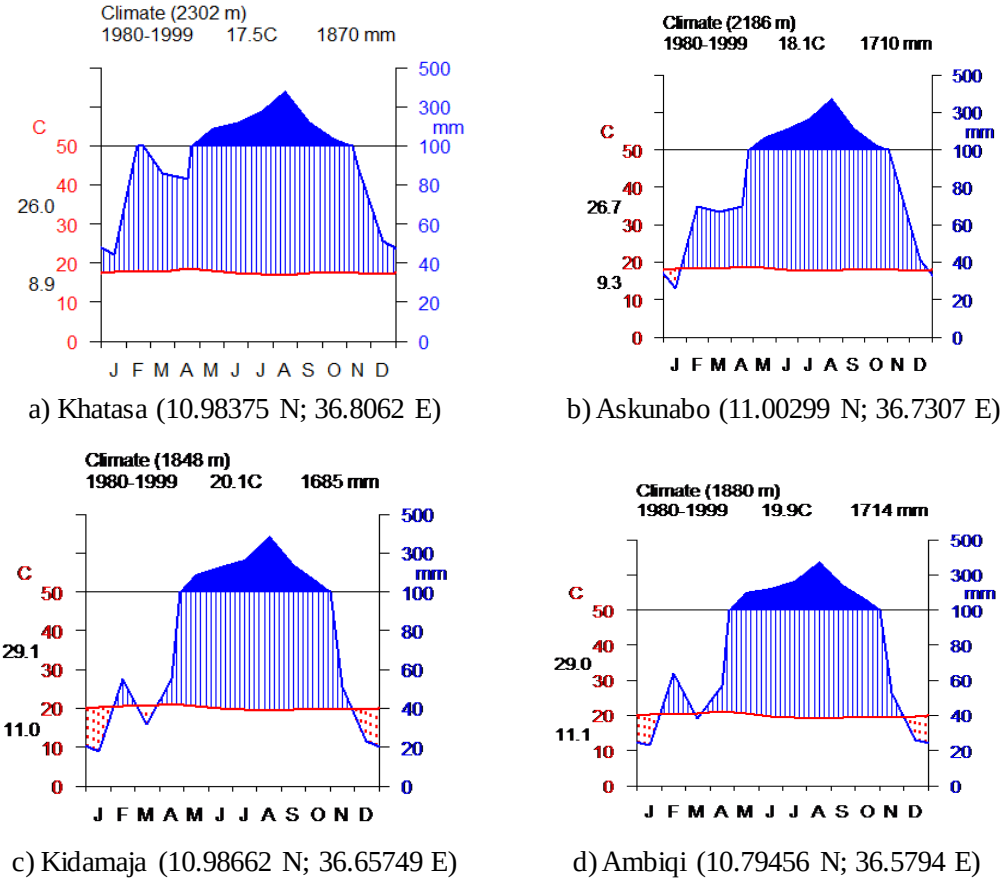
Table 1. Number and total area of plots investigated along line transects in each forest patch.

Forest patch	Ambiqi	Bradi	Degera	Kidamaja	Askunabo	Khatasa	Total
No. of Line Transects (LT)	5	7	6	5	7	6	36
Orientation of LTs	*SW-NE*	*E-W*	*SW-NE*	*SW-NE*	*SW-NE*	*SW-NE*	-
Plot Range	115-130	1-31 and 56	32-55	95-113	57-94 and 153-156	132-152	1-156*
No. of Plots (P)	16	32	24	18	42	22	154
Total Area (ha)	0.64	1.28	0.96	0.72	1.68	0.88	6.16
P/LTs (Ratio)	3.20	4.57	4.00	3.60	6.00	3.67	4.28

**** Note:*** *two numbers, 111 and 114 were not used as plot numbers. E - east, W – west, SW – southwest, NE - northeast*

Climate: Gemechu (1977) classified the rainfall pattern of the study area as unimodal. Most of the study area gets rain for at least nine months with variable intensity. The annual precipitation ranges between 1685 and 1870 mm. The highest precipitation of wettest month (August) is 388 mm at Khatasa; while in the driest

month (January) it is 18 mm at Kidamaja. The wettest months are May to October with high peaks in August; whereas the driest months are December to February for all study sites except Khatasa (Figure 2). The annual mean temperature of the study area ranges between 17º C and 22º C. The highest annual mean temperature was recorded at Kidamaja; whereas the lowest was recorded at Khatasa.



a) Khatasa (10.98375 N; 36.8062 E) b) Askunabo (11.00299 N; 36.7307 E)

c) Kidamaja (10.98662 N; 36.65749 E) d) Ambiqi (10.79456 N; 36.5794 E)

Figure 2. Clima diagrams for meteorological stations in the study area (Awi).

Vegetation data collection

A total of 154 sampling plots of each 400 m^2 (20 m x 20 m) were taken from all forest patches. The number of sampling plots varied per forest patch based on forest cover, altitudinal differences (gradients) and habitat variability of forest patches. The distance between two consecutive plots along a line transect was 200 m. The first line transect was aligned randomly at one side of the forest by avoiding the forest edge (at least 50

m into the forest). The distance between two parallel line transects was 300 m. The transects were laid against altitudinal gradients in order to capture representative samples of the forest.

The scientific and local names, habits and abundance for each woody species were recorded in each plot. Diameter of each woody species having a diameter of ≥ 2.5 cm at Breast Height (DBH) was measured using a tree caliper. When the boll of a tree was at breast height, diameter was measured above the tree ball. In cases where the tree or shrub branched at about breast height, DBH was measured separately for each branch that is each branch was considered as separate individual.

The heights of all individuals of woody species with DBH ≥ 2.5 cm was measured with a Hypsometer (Nikon Laser Rangefinder Forestry Pro) and meter tape as appropriate. For measuring abundance of seedlings of woody species 2 m x 2 m sub-plots, one at each corner and one at the center of each 400 m^2 quadrat (total area 20 m^2 per plot), were used. Seedling in this study is defined as individuals of a woody species having a DBH of below 2.5 cm or a height of below 1.5 m (Maria et al., 1995).

Botanical identification

All plant specimens were collected, temporarily tagged with plot numbers followed by English alphabets, pressed and transported to the National Herbarium (ETH) for identification and storage. Unidentified and identified specimens were identified and confirmed, respectively, by using the various volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Edwards et al., 1995; Phillips, 1995; Hedberg et al., 2003; Tadesse, 2004; Hedberg et al., 2006; 2009a; 2009b). Voucher specimens were deposited at the ETH and the Ethiopian Biodiversity Institute (EBI).

Data analysis

Floristic richness and diversity

Floristic richness, diversity and evenness indices and Whittaker's beta diversity index of the study area and sites were calculated using R Package 3.2 (R Core Team, 2021).

Forest structure

Frequency in this study is expressed as a percentage of the total number of plots in which individuals of a given species were recorded divided by the sum total number of the plots taken in the study area. The following formulas were used in Microsoft Excel spreadsheet programme.

$$F = \frac{P_i}{\sum_{i=1}^{s} P_i} \times 100,$$

Where, F is the frequency of a species and P_i is number of plots in which the i^{th} species (s) was recorded;

$$R_{fr} = \frac{F_i}{\sum_{i=0}^{s} F_i} \times 100,$$

Where, R_{fr} is the relative frequency of a species and F_i is frequency of the i^{th} species (s).

The study on the population structure, which is defined as the frequency distribution of individuals in arbitrarily defined DBH or height classes, was carried out for woody species based on most widely used DBH and height classes in Ethiopia (e.g. Dalle, 2015; Berhanu et al., 2017). Diameter was classified into nine classes of 5 cm interval and height into 10 classes of 5 m interval. DBH classes include: 2.5 – 7.5, 7.6 – 12.5, 12.6 – 17.5, 17.6 – 22.5, 22.6 – 27.5, 27.6 – 32.5, 32.6 – 37.5, 37.6 – 42.5 and >42.5. Height classes are ≤5, 5.1 – 10, 10.1 – 15, 15.1 – 20, 20.1 – 25, 25.1 – 30, 30.1 – 35, 35.1 – 40, 40.1 – 45 and > 45. To show the population structure, the density of individuals falling in the DBH or height classes were summed up and diagrams were produced using Microsoft Excel spreadsheet programme.

Woody species density in this study is expressed as number of individuals of a species per hectare. The density and relative density of woody species were computed in Microsoft Excel spreadsheet programme. The total species density, which is expressed as the sum total of all individuals of all species in a hectare was also computed. The relative density was calculated using the following formula:

$$R_{de} = \frac{D_i}{\sum_{i=1}^{s} D_i} \times 100,$$

Where, R_{de} is the relative density of a species and D_i is density of the i^{th} species (s);

Basal area (m^2 ha^{-1}) measured as the cross-section area of a tree at breast height, was computed from the measurement of DBH as follows in Microsoft Excel spreadsheet programme:

$B_a = \pi d^2/4$, where $\pi = 3.14$, B_a is basal area, and d is DBH (m).

However, since DBH was measured in centimeters, the formula was modified in such a way that the B_a will be in square meters. Thus, $B_a = \pi d^2/40{,}000$ or $0.0000785d^2$, where d is DBH in centimeters. The mean basal area of all investigated plots was converted to mean basal area per hectare.

The dominance and relative dominance were calculated as follows.

$D_o = B_i \times N_i$,

Where D_o is dominance of a species, B_i is mean basal area per species and N_i - number of individuals in the i^{th} species

$R_{do} = \frac{Do_i}{\sum_{i=0}^{s} Do_i} \times 100$,

Where, R_{do} is relative dominance and Do_i is dominance of the i^{th} species (s).

The significance of variations of richness and structure (density and basal area) among the forest patches were tested using One-Way ANOVA in PAST software Package (ver. 3.04) as these parameters are some of the most affected by disturbance and other factors (Hammer et al., 2001; Franklin et al., 2002).

Importance value index

The Importance Value Index (IVI) of a species signifies the sum of its relative density (RDE), relative frequency (RFR) and relative dominance (RDO) (Kent and Coker, 1992).

IVI = RDE + RFR + RDO.

The IVI was computed in Microsoft Excel spreadsheet programme. Consequently, woody species having the least IVI values, species which are not well represented due to disturbance or other negative factors, were prioritized for the purpose of conservation and management interventions.

RESULTS

Floristic richness and diversity

A total of 212 species belonging to 169 genera and 79 families were recorded in the study area; 208 species in sampling plots and four species outside sampling plots (Table 2). In terms of habit, 122 species were woody (Liana 24, Shrub 62, Tree 36) and 90 were herbaceous. Angiosperms were represented by 204 species, gymnosperms by one species and Pteridophytes by seven species. Among the Angiosperms, the family Asteraceae was the richest family (18 species), followed by Acanthaceae and Fabaceae (13 species each), Euphorbiaceae (12 species) and Lamiaceae (10 species). Pteridophytes were represented by four families, namely Aspleniaceae (two species), Polypodiaceae (two species), Pteridaceae (one species) and Selaginellaceae (two species). *Juniperus procera* (Cuperessaceae) was the only species in Gymnosperms. The highest richness among the forest patches was recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forest patches. In terms of woody species richness, Askunabo was the richest, followed by Bradi, Khatasa, Degera, Kidamaja and Ambiqi forests. Khatasa forest harbored the highest richness of herbaceous species, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forests. The species, which were recorded outside sampling plots are *Echinops kebericho* Mesfin, *Erythrina brucei* Schweinf., *Guizotia abyssinica* (L. f) Cass. and *Sapium ellipticum* (Krauss) Pax. *G. abyssinica* is a cultivated crop which was collected as an escape from areas of cultivation. No significant variations of woody species richness were found among the forest patches in the study area ($P > 0.05$).

Table 2. Floristic richness of the six forest patches in the study area.

No.	Forest Patch	Woody Species Richness	Herbaceous Species Richness	Total Richness
1	Ambiqi Forest	55	30	85
2	Askunabo Forest	64	44	108
3	Bradi Forest	62	48	110
4	Degera Forest	56	21	77
5	Khatasa Forest	58	53	111
6	Kidamaja Forest	55	23	78
	Total	**122**	**90**	**212**

The Shannon diversity index and evenness of the study area were 3.7 and 0.8, respectively (Table 3). Among the forest patches, the highest Shannon index was observed in Bradi forest, followed by Kidamaja, Degera, Khatasa, Askunabo and Ambiqi. Shannon evenness value was also in the same order with little variations, the highest being for Bradi and Kidamaja forests and the least evenness for Ambiqi forest. The Whittaker's beta diversity index of the study area was 5.6.

Table 3. Indices of diversity and evenness of the forest patches in the study area

No.	Forest Patch	Evenness index (J)	Alpha Diversity index (H')	Beta Diversity index (ß)
1	Bradi Forest	0.81	3.35	5.45
2	Degera Forest	0.79	3.18	4.66
3	Askunabo Forest	0.74	3.08	6.48
4	Kidamaja Forest	0.81	3.24	4.88
5	Khatasa Forest	0.78	3.18	6.01
6	Ambiqi Forest	0.73	2.91	5.94
	Study area	**0.8**	**3.7**	**5.6**

Vegetation structure

Woody species frequency and density

The most frequent woody species in the study area was *Rytigynia neglecta* (83%), followed by *Croton macrostachyus* (68%), *Vepris dainellii* (62%), *Albizia schimperiana* (57%) and *Maytenus arbutifolia* (54%). Generally, about 95% of the species had below 50% frequency; 33% of the species each occurred in a single plot; while 12.5% of species each occurred in two plots. The relative frequency of species was between 0.04 and 6% with similar orders as their frequencies.

The total abundance of woody species with DBH ≥ 2.5 cm in the study area was 13380 stems; while the total density was 2172.1 stems ha^{-1}. The top most abundant species with abundance value of above 500 individuals were *Rytigynia neglecta, Rothmania urcelliformis, Deinbollia kilimandscharica, Albizia gummifera, Croton macrostachyus, Bersama abyssinica, Vepris dainellii* and *Maytenus arbutifolia*.

R. neglecta was the most abundant species with abundance of 1349 individuals and a density of 219 stems ha^{-1}. The first five species have densities of 100 stems ha^{-1} and above. Generally, 25% of the species have densities of one stem ha^{-1}. The relative density ranged between 0.01 and 10.1%, the highest being for *R. neglecta*.

The highest density was documented in Ambiqi forest (2437.5 stems ha^{-1}), followed by Degera (2340.6 stems ha^{-1}), Khatasa (2179.5 stems ha^{-1}), Kidamaja (2158.3 stems ha^{-1}), Bradi (2080.5 stems ha^{-1}) and Askunabo (2059.5 stems ha^{-1}) forests. Consequently, 22 species scored a density of 100 stems ha^{-1} or higher in all forest patches. No significant variations of the mean densities of woody species were found among the forest patches in the study area ($P > 0.05$).

Basal area and dominance

The total basal area and dominance of woody species were 41.2 and 23.1 m^2 ha^{-1}, respectively. Generally, 11 species such as *Albizia schimperiana, Prunus africana, A. gummifera, Apodytes dimidiata, Croton macrostachyus* and *Ekebergia capensis* scored a basal area of 1.0 m^2 ha^{-1} and above, which were among the top dominant species. Ambiqi forest had the highest basal area (57.4 m^2 ha^{-1}), followed by Askunabo (43 m^2 ha^{-1}), Khatasa (40.5 m^2 ha^{-1}), Bradi (37 m^2 ha^{-1}), Kidamaja (35 m^2 ha^{-1}) and Degera (34.5 m^2 ha^{-1}) forests. In terms of dominance, Khatasa forest had the highest dominance (28.7 m^2 ha^{-1}), followed by Ambiqi (28 m^2 ha^{-1}), Askunabo (26 m^2 ha^{-1}), Kidamaja (25.3 m^2 ha^{-1}), Bradi (23.5 m^2 ha^{-1}) and Degera (20.8 m^2 ha^{-1}). No significant variations of basal area of woody species were found among the forest patches in the study area ($P > 0.05$)

Importance value index of woody species

The importance value index of woody species in the study area ranged from 0.05 to 16.8. The highest IVI was documented for *Rytigynia neglecta*. Species such as *Albizia gummifera, A. schimperiana, Prunus africana, Croton macrostachyus*, *Rothmania urcelliformis* and *Apodytes dimidiata* were among the most

important species. Generally, 50.5% of the species had IVI of below one, 12% IVI of one and 37.5% above one.

The IVI of species in the forest patches moderately varied. For example, the highest IVI of species was in Kidamaja forest (*A. schimperiana*, 47.1), followed by Khatasa (*A. dimidiata*, 38.4), Askunabo (*D. kilimandascharica*, 37.2), Degera (*R. urcelliformis*, 33.8), Ambiqi (*C. spinarum*, 32.7) and Bradi (*R. urcelliformis*, 25.2). Generally, 14 woody species had IVI values of 20 and above, while the majority had below 20 in the forest patches.

Diameter and height class distribution

The DBH and height class distribution of woody species density in the study area showed an Inverted-J shaped structure (Figure 3). All DBH classes were represented by at least some individuals even though the highest density was concentrated in DBH classes below 12.5 cm. The highest DBH was recorded for one individual of *Ekebergia capensis* (270 cm). Twenty-four individuals of seven species, namely *Ekebergia capensis, Prunus africana, Schefflera abyssinica, Albizia gummifera, A. schimperiana, Juniperus procera* and *Apodytes dimidiata* had a DBH of 100 cm and above.

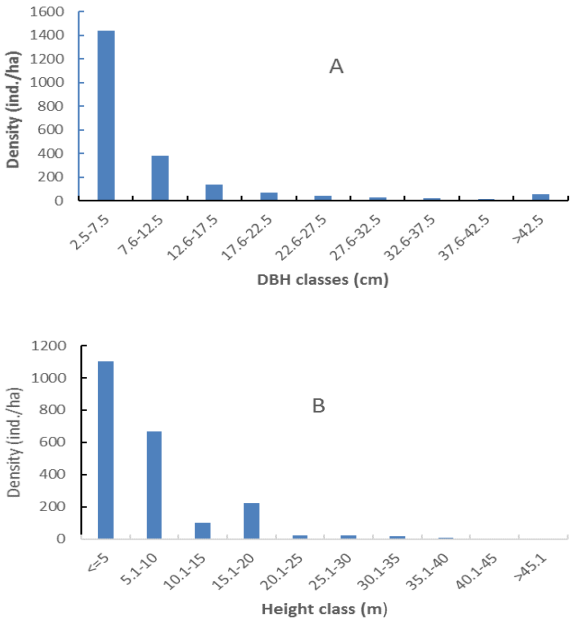


Figure 3. Distribution of population densities in DBH (A) and height (B) classes in the study area.

The height class distribution showed more or less similar pattern to DBH classes. The majority of individuals were accumulated at the lower height classes (< 10 m). In each forest patch, most individuals were accumulated in lower DBH and height classes (Figure 4).

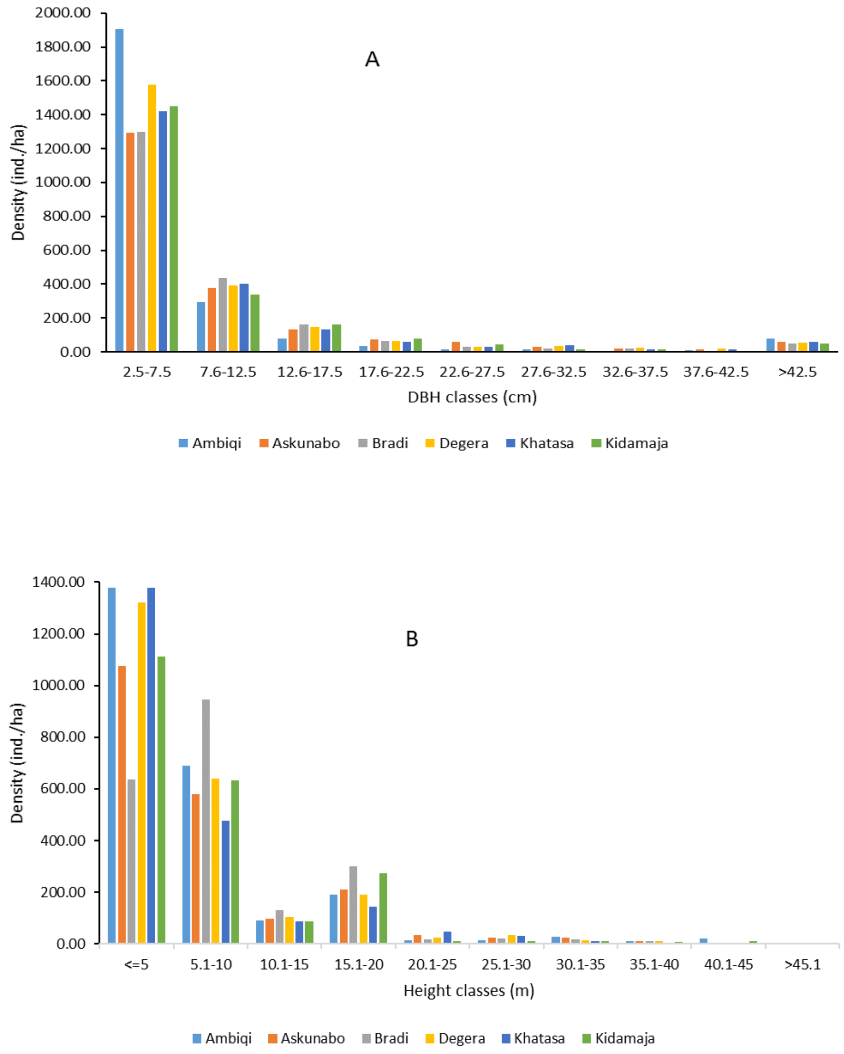


Figure 4. Distribution of population densities in DBH (A) and height (B) classes for each forest patch.

The analysis of population structure of 28 selected tree species in nine DBH classes revealed five population structure patterns (Figure 5). The first pattern was an Inverted-J shaped in which the highest number of individuals were present in lower DBH classes and their presence decreased towards higher classes. Tree species in this category were *Albizia schimperiana*, *A. gummifera*, *Celtis africana*, *Prunus africana*, *Allophylus abyssinicus*, *Croton macrostachyus*, *Euphorbia abyssinica*, *Ficus sur*, *Maytenus obscura* and

Mimusops kummel. The second pattern was unimodal/bell shaped in which a higher proportion of species were present in intermediate DBH classes and the trend decreased in both directions (lower and higher DBH classes). The species in this category were *Dracaena steudneri, Stereospermum kunthianum* and *Acacia abyssinica*. The third pattern was J shaped in which a higher proportion of individuals were present at higher DBH classes and the trend decreased towards lower DBH classes. This pattern was exhibited by *Apodytes dimidiata*. The fourth pattern was a Broken Inverted-J shaped where individuals were absent at intermediate or higher DBH classes. *Ehretia cymossa, Ficus thonningii, Lepidotrichilia volkensii, Olea capensis* subsp. *macrocarpa, Pittosporum viridiflorum, Ritchiea albersii, Millettia ferruginea* and *Cordia africana* were in this category. The fifth pattern lacked individuals at lower and intermediate DBH classes and some mature individuals were present at the highest DBH classes. Trees such as *Juniperus procera, Ekebergia capensis, Euphorbia ampliphylla, Polyscias fulva, Schefflera abyssinica* and *Syzygium guineense* exhibited this pattern.

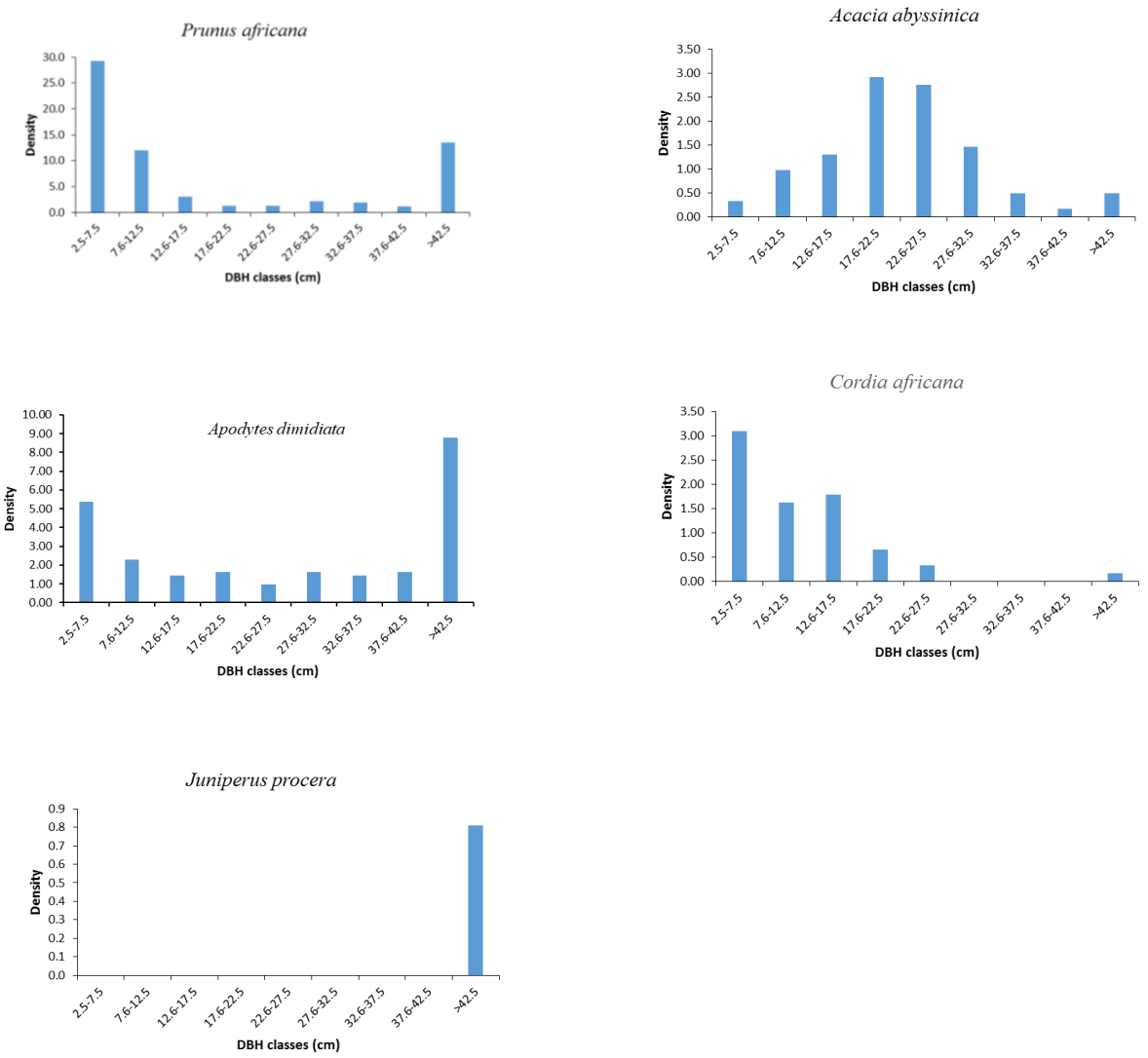


Figure 5. Representative population structure patterns of tree species in the study area.

DISCUSSION

Richness and diversity

The study revealed that the study area harbored rich floristic composition and diversity. Accordingly, the number of woody species recorded in this study is higher than similar studies conducted in the Dry evergreen Afromontane Forests of Ethiopia such as Zege Peninsula Forest (Aleign et al., 2007), forests of central plateau of Shewa (Bekele, 1993), Adelle and Boditi Forests (Yineger et al., 2008), Amba Mariam Forest (Tilahun et al., 2011), Tara Gedam and Abebaye Forests (Zegeye et al., 2011), Zengena Forest (Tadele et

al., 2013) and Kuandisha Forest (Berhanu et al., 2017). This could be partially attributed to the ecological diversity of the present study area, which covers wide altitudinal ranges. It has been long known that altitude plays paramount role in plant distribution and richness/diversity and the underlying direct causes such as climate, air pressure and soil properties are directly related to altitude (Brown and Lomolino, 1998; Barry, 2008). However, the present study area is not as much of some of similar study areas such as central plateau of Shewa (Jibat forest) in terms of altitudinal coverage (Bekele, 1993). Thus, the most important justification for such variations could be climate variability (Schmitt et al., 2010) and forest disturbance (Økland, 1990). The present study area is found in the intermediate zone between moist and dry climates and harbors a diverse assemblage of both the dry and moist evergreen Afromontane Forest species and has been classified as a new vegetation type (Berhanu et al., 2018). Although disturbance is present in some of the forest patches in the present study area, the forests are relatively well protected, which contributed in conserving many of economically and ecologically useful canopy species. On the other hand, in terms of herbaceous species, a smaller number of species were recorded than other study areas (Yineger et al., 2008; Tilahun et al., 2011). The low number of herbaceous species richness may be attributed to the closed canopy cover of the forest patches in the study area. According to Friis (1986) and Murphy and Lugo (1986), herbaceous species cover is usually inversely proportional to canopy cover. That is closed canopy sites of forests have poor herbaceous cover and vice versa depending the amount of light penetration.

The order of families in terms of species richness is in accordance with other studies in that Asteraceae is reported to be the richest family in northwestern and central Ethiopian forests (Yineger et al., 2008; Tilahun et al., 2011; Lulekal, 2014) and in this study. On the other hand, Berhanu et al. (2017) documented that the family Fabaceae was the richest family followed by Euphorbiaceae and Asteraceae in Kuandisha dry evergreen Afromontane Forest fragment. Fabaceae is also known to be the richest family in Ethiopia followed by Poaceae, Asteraceae and Euphorbiaceae (Kelbessa and Demissew, 2014).

The least Shannon diversity index in Ambiqi forest could have mainly resulted from severe disturbance such as selective logging and grazing (Maguran, 2004). The high diversity index in other forest patches may be attributed to the relatively less disturbance and high evenness values. The correlation between Shannon diversity index and evenness values was positive and strong ($r = 0.9$; $P < 0.05$) in the study area. Species diversity increases when the populations have more even abundances and vice versa (Maguran, 2004; Lean and Maclaurin, 2016). In other words, many of the species were rare and the distributions of individuals of the species were even ($J \geq 0.7$). Shannon diversity index is sensitive to the presence of rare species and high evenness values (Maguran, 2004; Schmitt et al., 2010). Consequently, the diversity index was higher than other forests in the DAF (Dry evergreen Afromontane Forest) such as Tara Gedam and Abebaye forests (Zegeye et al., 2011), Amba Mariam forest (Tilahun et al., 2011) and Zengena forest (Tadele et al., 2013). The beta diversity index was also high ($\beta = 5.6$), which was strongly and positively correlated with richness of forest patches ($r = 0.7$, $P < 0.05$). According to Maguran (2004), a beta diversity index greater than five can be considered as high value and this indicates a high turnover in and among the forest patches.

Structure of forests and woody species

Frequency and density

A significant portion of the species were rare in the study area. The most frequent species were pioneer species such as *Croton macrostachyus* and *Bersama abyssinica* (Bekele, 1993) and the common weed *Achyranthes aspera* (Townsend, 2000), which are also common in the disturbed forests and forest edges of the DAF and MAF (Moist evergreen Afromontane forest) (Townsend, 2000; Friis et al., 2010). *Vepris dainellii* is an endemic species, which was common in most (61%) of the sampling plots. According to Gilbert (1989), the species occurs in the understory of moist montane forests, often with *Podocarpus falcatus* or *Pouteria adolfi-frederici*, less often at forest margin or in secondary growth. Bekele (1993) reported similar results about the species in Jibat forest. The other most frequent species, namely *B. abyssinica* and *Maytenus arbutifolia* are common species in disturbed and secondary forests with early

developmental stage in the DAF and MAF and they are usually strongly associated with overgrazing (Tesfaye and Berhanu, 2006; Berhanu et al., 2017).

Canopy trees such as *Albizia schimperiana* and *A. gummifera* are also dominant species in the Afromontane Forests between altitudes 1600 and 2600 m and they are widely distributed in eastern Tropical Africa (Thulin, 1989; Friis et al., 2010). *A. gummifera* and *C. macrostachyus* have also been reported to be the most frequent species in Tara Gedam and Abebaye forests, respectively (Zegeye et al., 2011). On the other hand, the liana species *Landolphia buchananii*, which was also highly frequent in the study area, is mainly of a lowland species in gallery forests, woodlands, often on or near rocks between 1300 and 1550 m (Leeuwenberg, 2003). Hence, its high presence above 1550 m (up to 2100 m) in the study area is unusual. The species has also been reported to be the second most dominant species next to *Coffea arabica* in moist evergreen Afromontane forests of southwestern Ethiopia (Senbeta, 2006). Thus, its high presence in the study area may be attributed to the transitional climate from moist to dry climates. Generally, except few variations, many of the most frequent species in the study area were also the most frequent in each forest patch.

The overall density of woody species with DBH ≥ 2.5 cm was considerably lower than other forests such as Zege Peninsula, Tara Gedam and Kuandisha forests in the DAF (Alelign et al., 2007; Zegeye et al., 2011; Berhanu et al., 2017) and moist evergreen Afromontane forests of southwestern Ethiopia (Senbeta, 2006). The composition of the top most abundant species was also different from such forests except *Rytigynia neglecta, Croton macrostachyus, Maytenus arbutifolia* and *Bersama abyssinica* that are gap fillers and pioneer woody species in disturbed sites, secondary forests and forest edges (Bekele, 1993; Dalle and Fetene, 2004; Bekele, 2007; Berhanu et al., 2017). Some climax tree species such as *Albizia gummifera* and *Millettia ferruginea* were also reported as having the highest density in Tara Gedam and Zege Peninsula forests, respectively (Alelign et al., 2007; Zegeye et al., 2011).

Generally, about 7% of the species accounted for 53% of the total stem density and also had the largest density of seedlings. This has partly to do with disturbance as species such as *Maytenus arbutifolia* and *Justicia schimperiana* favor disturbance and sudden openings of forests for their germination, growth and establishment (Dalle and Fetene, 2004; Tesfaye and Berhanu, 2006; Berhanu et al., 2017). In contrast, seedlings of *Albizia gummifera* and *A. schimperiana* were abundant in openings near mother trees where the sites were relatively undisturbed. According to Muhanguzi et al. (2002), *A. gummifera* has a very high rate of seed germination under shade or light conditions, which is an escape mechanism from mortality factors.

The absence of seedlings of some of the canopy trees such as *Juniperus procera* and *Syzygium guineense* is highly attributed to disturbance (trampling and seedling removal), seed predation, habitat unsuitability and life history strategy. Disturbance and seed predation have been noted to play their own role in reducing the seedling population of woody species (Teketay, 2005b; Wassie et al., 2009). Consequently, no seedlings of *Juniperus procera* were encountered in the study area (Khatasa forest) during the study period, which is in contrast to the reports from the local people. Similarly, no or poor regeneration of *J. procera* under natural conditions have been reported elsewhere in Ethiopia (Sharew, 1982; Aynekulu et al., 2009) and Saudi Arabia (El-Juhany et al., 2008). Consequently, it has been noted that *J. procera* will not regenerate in its own shade and its presence as a forest tree is largely dependent on fire, either natural or man-made, which removes the deep layer of humus and exposes the soil mineral for seed germination, seedling growth and survival (Sharew, 1982; White, 1983; Orwa et al., 2009).

Basal area and dominance

The total basal area of woody species is generally in the range provided for tropical and subtropical dry and wet forests of the world (Murphy and Lugo, 1986). Moreover, the range of the total basal area of woody species in the forest patches of the study area was comparable to that of Moist evergreen Afromontane Forests of southwestern Ethiopia (Senbeta, 2006) and Dry evergreen Afromontane Forests of central

Ethiopia (Lulekal, 2014). The lower and higher DBH classes contributed most to the total basal area, which was also supported by other studies (Bekele, 1993; Senbeta, 2006; Tadele et al., 2013; Lulekal, 2014; Berhanu et al., 2017).

The basal area and dominance value of woody species was higher than some forests such as Zengena Forest (Tadele et al., 2013), Kuandisha Forest (Berhanu et al., 2017), Hugumburda Forest (Aynekulu, 2011) and Adele and Boditi Forests (Yineger et al., 2008). On the other hand, the basal area of woody species reported from Tara Gedam is higher than the present study area (Zegeye et al., 2011). According to Wassie et al. (2005), churches and monasteries harbor many of the forests with the oldest and large-sized individuals of trees in north Gondar.

Importance value index

The importance value index (IVI) of woody species in the study area was generally lower compared to other forests in the DAF (Zegeye et al., 2011; Tadele et al., 2013; Lulekal, 2014; Berhanu et al., 2017). The variability of IVI values of species among the forest patches is partly attributed to the conservation status of some of the highly dominant species in those forests. *Albizia schimperiana* and *A. gummifera*, for example, which are highly valued for their shade for livestock and humans and protected by the community, were the most abundant and dominant species having the highest IVI values in Ambiqi, Kidamaja and Bradi forest patches. Habitat suitability also plays its own part. For instance, *Carissa spinarum* and *Croton macrostachyus* were the most important species in the highly disturbed Ambiqi forest, which are usually indicators of degraded or seriously disturbed forests (Bekele, 1993; Friis et al., 2010; Berhanu et al., 2017). On the other hand, some of the least important species in the forests of the study area such as *Syzygium guineense* and *Salix subserrata* are usually important species in the Riverine vegetation, beside streams and lake shores; occasionally also transgressing into humid secondary evergreen bushland and woodland (Meikle, 1989; Friis, 1995; Friis et al., 2010). Moreover, least important species in the study area such as *Steganotaenia araliacea* and *Stereospermum kunthianum* are usually found in open woodlands and savanna

elsewhere (Hedberg and Hedberg, 2003; Bidgood, 2006) and their least IVI values in the study area may be attributed to unsuitable habitats. On the other hand, *Rhus glutinosa* subsp. *glutinosa* had been excessively exploited for its high-quality wood for traditional house construction as it is resistant to termites and its use for firewood, farm tools and tool handles in the study area and elsewhere (Bekele, 2007). Thus, its status in the study area is very poor having the least IVI value with rare presence as a result of overexploitation.

Population structure of forests and woody species

The population structural patterns of all forests of the study area and individual forest patches generally indicated a healthy status of those forests; which was Inverted-J shaped. Similar findings have been reported elsewhere in Ethiopia (Senbeta, 2006; Beche, 2011; Tadele et al., 2013; Berhanu et al., 2017). However, that was contrary to the fact that is clearly seen from patterns of population structures of each tree species. Consequently, an investigation of the population structure of many of the tree species revealed that they lacked individuals at various DBH and height classes. Moreover, a highly skewed Inverted-J shaped population pattern may to some extent indicate abnormal distribution of population densities in the forests undergoing secondary development after forest clearance or disturbance such as selective logging of individuals having higher DBH classes (Friis, 1986; Bekele, 1993). And under such circumstances, it is usually difficult to generalize based on the shape of the population pattern of the whole forest alone as indicator of forest health. Consequently, the Inverted-J shaped distribution pattern of forest patches should be interpreted with caution (Westphal et al., 2006; Ducey, 2010). The pertinent reason, which was observed from population patterns of forest patches, was the “compensatory effect”; where populations of one species compensate for the missing populations of another species in various DBH and height classes. Hence, the population pattern of each tree species was found to be comparatively useful for forest health indicator in the study area as population absences and presences for each tree species were clearly detected in various DBH and height classes.

Different population patterns of tree species are usually caused by various factors such as selective cutting, disturbance, shade-intolerance and life history strategy (Teketay, 2005a; Bin et al., 2012). The five population patterns revealed in this study are attributed to those factors. The first pattern, which is Inverted-J shaped is usually an indicator of healthy population status of a species (Teketay, 2005a; Senbeta, 2006; Alelign et al., 2007; Tadele et al., 2013; Berhanu et al., 2017) even though the density of individuals in various DBH or height classes slightly varied among studied forest patches. The second pattern, which is unimodal or bell-shaped, is highly attributed to poor regeneration and selective removal of individuals with lower and higher DBH classes; while populations in the middle classes are left. This pattern has rarely been reported in the DAF (Tadele et al., 2013; Lulekal, 2014) and MAF (Senbeta, 2006; Kelbessa and Soromessa, 2008).

The third pattern, which was a J shaped distribution, is an indicator of a highly disturbed forest with poor reproduction and selective removal of individuals with lower DBH classes (Bekele, 1993; Senbeta, 2006). That is intermediate and mature individuals are usually left in the population whereas lower DBH classes are removed for various uses such as firewood, construction and farm implements (Bekele, 1993). The fourth pattern with Broken Inverted-J shaped structure lacked individuals in intermediate or higher DBH classes. This pattern is caused by selective removal of mature individuals for construction purposes (Senbeta, 2006; Alelign et al., 2007).

The fifth pattern lacked all of the individuals except the highest DBH class (>42.5 cm). This pattern is an indicator of lack of regeneration and establishment of populations of a species after a major disturbance such as clear-cutting for agriculture, grazing land or settlement, leaving few mature individuals as shade trees (Friis, 1986) or a life history strategy where mother trees negatively influence the germination of seeds and establishment of seedlings under their canopies (White, 1983; Bin et al., 2012). This pattern has rarely been reported for tree species, namely *Juniperus procera* and *Erythrina brucei* in the highly disturbed forests of the DAF (Bekele, 1993; Tadele et al., 2013).

CONCLUSION AND RECOMMENDATION

The hypothesis was rejected in that species richness, density and basal area of the six forest patches of the study area were not significantly different. However, a number of plant species in the study area were found to be at conservation risk. Despite this fact, the population structure patterns of the forests of the study area and each forest patch revealed that the study area and the forest patches were in healthy status. Five population density patterns were evident for 28 tree species investigated, namely Inverted-J shaped, J shaped, Broken Inverted-J shaped, unimodal/bell-shaped and a fifth pattern where only mature individuals were represented. The majority of species had IVI values below one in each forest patch and in the study area in general. Moreover, the population structure of tree species, except naturally rare plants, confirmed the absence of individuals in various DBH classes that contributed to the least IVI values.

Using population structure patterns in various DBH and height classes to show the status of forests and individual tree species has been largely employed in Ethiopia and elsewhere. However, the use of such patterns particularly for forest patches was not that useful as realized in this study because of "compensatory" effects of individuals of different species in various DBH or height classes. Thus, it is highly recommended to use population structure patterns of each tree species and interpret the results with caution as some tree species may show different patterns because of life strategy or other natural factors. Degraded and threatened forests and species require maintenance and restoration activities, enrichment planting in suitable areas and protection of sites. Special emphasis should also be given for the conservation of species with low IVI values.

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IMPACTS OF PARTHENIUM WEED (*PARTHENIUM HYSTEROPHORUS* L.) ON SELECTED SOIL CHEMICAL PROPERTIES IN HIDHABU ABOTE DISTRICT, ETHIOPIA

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ABSTRACT: *Parthenium hysterophorus* L. has become a major environmental, social, and economic threat in Ethiopia. Therefore, examining its impacts on soil chemical properties is vital to designing future management strategies. A total of 36 soil samples were collected from *P. hysterophorus* invaded and non-invaded sites. A simple *t*-test was conducted to examine the impacts of *P. hysterophorus*'s invasion on soil chemical properties between invaded and non-invaded sites per depth. Significant pairwise differences ($p<0.05$) were observed among means of soil pH, calcium, electrical conductivity, phosphorus, and magnesium between invaded and non-invaded sites. The threats of this species on native biodiversity, soil chemical properties, and the economy will be high in the future unless management action is undertaken. This study suggests that all relevant stakeholders should be organized to combat the expansion of the species to new areas.

Keywords: Biological invasion, Impact of invasion; Parthenium hysterophorus, *Soil*

INTRODUCTION

Biological invasion is one of the main drivers of biodiversity loss and also the second most common threat next to habitat destruction and ecosystem degradation (Thapa et al., 2018). They have affected natural processes, homogenized flora caused the extinction of species, compromised agricultural production (Zuberi et al., 2014), and damaged ecosystem resources (Namkeleja et al., 2014).

Parthenium hysterophorus L. is an annual herb that aggressively colonizes disturbed sites (Zuberi et al., 2014). It is considered one of the '100 most invasive species in the world (GISD, 2018). It has accidentally been introduced into several countries and has become a series of agricultural and rangeland weeds in parts of Australia, Asia, Africa, and the Pacific Islands. In more than 45 countries, it is reported as a major weed in field crops (Bajwa et al., 2018), with yield losses estimated in millions of dollars (Saini et al., 2014).

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Parthenium hysterophorus is one of the top 20 invasive alien plants found in Ethiopia (Shiferaw et al., 2018) and the high spread of *P. hysterophorus* in the country has become a major threat to the various ecosystems (Shiferaw et al., 2018) and socioeconomic welfare (Tewelde and Mesfin, 2018). It poses high negative impacts on native biodiversity, agricultural lands, soil physical and chemical properties, rangeland resources, national parks, waterways, roadsides, urban green spaces, therefore leading to economic and social consequences (Zuberi et al., 2014; Hundessa, 2016). Ethiopian farmers describe it using the term "Faramsisa" in Afan Oromo, meaning "sign off"/"leave your farm" (Zuberi et al., 2014; Fite, 2017) which shows how this invasive weed is economically important. *P. hysterophorus* also affects human and animal health (McConnachie et al., 2011). In humans, it causes problems like asthma, bronchitis, dermatitis, and pollinosis. It also causes dermatitis with pronounced skin lesions and a large amount of *P. hysterophorus* L. in feed can kill cattle and buffalo (Kaur et al., 2014).

Parthenium hysterophorus prefers neutral to alkaline pH soils although it reacts to a wide variety of soils. It tolerates infertile, shallow, saline, and sodic soils. Its invaded sites were identified as having mostly sandy loam soil with a pH ranging from 5.4 to 7.4 (Kaur et al., 2014). Seeds of *P. hysterophorus* can germinate during any season of the year if moisture is available. It can keep its viability for an extended period and may grow under very harsh environmental conditions. Etana et al. (2011) reported that *P. hysterophorus* can extract nutrients from nutrient-deficient soils leading to high tissue levels of nitrogen phosphorus, potassium, and other macro and micronutrients, and recommending its manure for field crops.

A high amount of above-ground biomass along with the upper decomposition rate within the *P. hysterophorus* invaded area may lead to the observed increase in organic matter and nitrogen content (Timsina et al., 2011). According to Timsina et al. (2011) the increase in soil pH within the *P. hysterophorus* invaded area is due to the allelopathic chemicals discharged by the species into the soil which has no direct effect on the rise in soil nutrients, like nitrogen and phosphorus. The allelopathic compounds may, however, kill different soil microorganisms, and also the decomposition of microorganisms may cause increases in

the amount of nutrients within the soil. *P. hysterophorus* L. grows in a very large choice of habitats and causes changes in above-ground vegetation as well as in below-ground soil nutrients (Timsina et al., 2011). These all are reported as the results of its concreted traits or its considerable phenotypic variation that may potentially promote invasiveness and thus, colonizing ability on soils across a broad range of habitat conditions. There was no research done in the study area concerning *P. hysterophorus* invasion and its impacts. Therefore, the purpose of this study was to examine the impacts of *P. hysterophorus* on selected soil chemical properties.

MATERIALS AND MEHTHODS

Description of the study area

The study was conducted in the Hidhabu Abote woreda/district, Ethiopia. Hidhabu Abote Wereda is one of the 14 woredas of the North Shewa Zone of Oromia Regional State and is located 34 km from the zonal capital of Fitche, and 146 km from the capital Addis Ababa. Hidhabu Abote is located at 9° 50′ 0″ N, 38° 30′ 0″ E in Ethiopia (Figure 1). It is bordered on the south by Kuyu, on the west by Wara Jarso, on the north by the Jamma river which separates, and on the east by Degem woreda.

The study area is characterized by a bimodal rainfall pattern with the main rainy season extending from July to September and the short season extending from March to May. The average annual rainfall and mean annual minimum and maximum temperature of the area based on the last ten years (2009-2017) records were 1014 mm and 8.57°C and 20.87°C respectively (Ababu, 2022). The agroecological zone of the woreda stretches between *Dega* (cool, humid highlands), *Weyena-dega* (mild, sub-humid highlands), and *Kola* (warm, semi-arid, lowlands) which covers about 12%, 73%, and 13.7% respectively (Ababu, 2022). The study woreda has a very diverse slope, ranging from flat lands (< 3%), a slope that accounts for 8% up to a very steep (> 60%) slope although the proportion is too small (< 0.1%) (Ababu, 2022). The major soil type of the study area is Nitisols. The soil is clay textured with a pH of 5.56, low content of nitrogen (0.15%), organic matter (1.42%), available phosphorous (4.36pmm), and moderate CEC (21.67 MEQ/100 g soil).

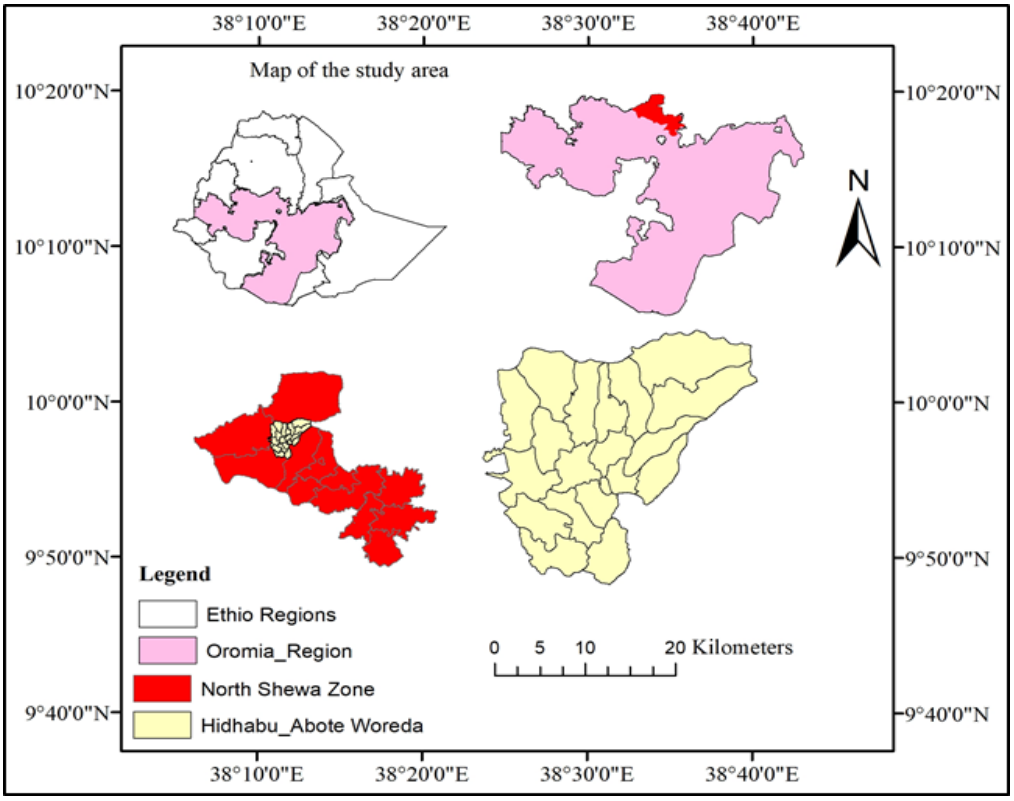

Figure 1. Map showing the study area.

Research design and sample collection methods

Reconnaissance survey

The reconnaissance survey was done to get information about the presence and the invasion area of *P. hysterophorus* in the study area. This was done by discussing with the Hidhabu Abote Agricultural office of the districts in the North Shewa Zone of the Oromia Region. This area was selected because it is one of the invaded areas in the North Shewa Zone. Field observation was also done to spot the invaded and non-invaded sites.

Sample collection

Soil samples were collected from invaded and non-invaded sites to test the soil pH, Nitrogen (N), carbon (C), phosphorus (P), electric conductivity (EC), exchangeable calcium (Ca^{2+}), and magnesium (Mg^{2+}) as these parameters used to determines soil fertility (Bai and Wang, 2011).

Sampling design

To examine the effect of *P. hysterophorus* on soil chemical properties, the study area was stratified into two categories (i) *P. hysterophorus* un-invaded site, and (ii) *P. hysterophorus* invaded site. The road is a means of entryway for invasive alien plant species due to the long-distance dispersal of propagules by vehicles (Ahmad et al., 2019). Therefore, sampling plots were laid on grazing land 10 m away from the road along a uniform slope gradient. In each category, three transects, 1 km long, were established. Within each transect, three 20 m × 20 m quadrats were established at every 500 m intervals making a total of 18 quadrates. Nested sub-plots of 1 m × 1 m (4 at the corner and 1 at the middle of the plot) were established to collect the soil sample.

Soil sample collection

In each subplot, using a core sampler auger, composite soil samples were taken at the depth of 0-20 and, 20-40 cm from the four corners and center of each quadrat after removing litter. Finally, 36 soil samples collected from each sub-plot were mixed homogenously and packed in a separate labeled plastic bag, and transported to Haramaya University soil laboratory for analysis.

Soil chemical analysis

The soil samples were oven-dried at 105°C for 24 h to remove the moisture of the sampled soil. Then, the grinded soil was passed through a 2 mm pore sieve for homogenization before being subjected to analysis. Soil pH, electrical conductivity and exchangeable basis were determined following the procedure of van Reeuwijk (2002. The pH of the soil was measured with a digital pH meter in the supernatant suspension in H_2O at the ratio of 1:2.5 (soil: water solution) using a combined glass electrode pH meter. The electrical conductivity (EC) of the soil 1:2.5 (soil: water) was measured by an EC meter. The organic carbon of the soil was also determined by the Walkley and Black (1934) method. The organic carbon was determined through wet oxidation of organic carbon with excess potassium dichromate ($K_2Cr_2O_7$) solution in the strong acid (H_2SO_4) rapid titration method. Total nitrogen was determined by the micro Kjeldahl digestion and

titration method (Bremner and Hauck, 1982). Available phosphorus was analyzed using the Olsen sodium bicarbonate extraction solution (pH 8.5) (Olson et al., 1954) and the amount of available phosphorus was measured by spectrophotometer. Exchangeable bases (Ca^{2+} and Mg^{2+}) were extracted after leaching the soils with 1 N neutral ammonium acetate (NH_2OAc) solution. Exchangeable calcium and magnesium were determined by atomic absorption spectrophotometry (AAS).

Statistical analysis

A simple *t*-test was used to get the mean and the standard deviation of soil parameters in *P. hysterophorus* invaded and non-invaded grassland per soil surface separately. Using R statistical software, a paired samples *t*-test was used to compare the mean of each selected soil parameter in invaded and non-invaded sites per the two soil surfaces.

RESULTS

Impacts of *P. hysterophorus* on soil chemical properties

The row data value of the selected soil chemical properties obtained from the laboratory analysis was shown (Appendix 1). The mean and the standard deviation (SD) of the selected soil chemical properties in the invaded and non-invaded sites are presented in Table 1 and Table 2 respectively. The mean of soil pH (H20) in both the invaded and non-invaded sites was slightly lower in the upper soil surface. The result also showed that there was a significant mean difference in the amount of soil Ca ($p = 0.00$) and EC ($p = 0.04$) on lower soil surface. Similarly, a significant mean difference was observed in the score of soil Mg ($p = 0.02$) in the upper soil surface.

The mean of organic carbon varied from 1.52 to 1.75% on the upper soil and from 0.48 to 1.74 % on the lower surface in invaded and non-invaded sites, respectively. The mean of total varied from 0.11 to 0.11% on the upper soil and from 0.12 to 0.12 % in invaded and non-invaded sites respectively. The mean of available phosphorus values in invaded and non-invaded sites varied from 9.43 to 5.38 mg/kg on the upper soil surface respectively. Similarly, the mean of available phosphorus in invaded and non-invaded sites for

lower surface ranged from 19.41 to 4.52 mg/kg. The mean of soil electric conductivity (EC) of the invaded and non-invaded sites ranges from 0.08 to 0.02 dS/mol in the upper soil surface whereas 0.05 to 0.03 dS/mol in invaded and non-invaded sites per lower surface. The mean value of exchangeable calcium in invaded and non-invaded sites varied from 8.83 to 5.638 cmol (+) kg^{-1} in the upper soil layer respectively. In addition, the mean of soil exchangeable calcium content in invaded and non-invaded sites in the lower soil surface varied from 9.98 to 5.94 cmol (+) kg^{-1}. The mean values of exchangeable magnesium (Mg) in invaded and non-invaded sites varied from 1.62 to 2.79 cmol (+) kg^{-1} in the upper soil surface respectively. Similarly, the mean of Mg content in invaded and non-invaded sites in the lower soil surface varied from 2.09 to 2.59 cmol (+) kg^{-1} respectively.

Table 1. Mean and the standard deviation (SD) values for the selected soil parameters in P. hysterophorus L. invaded site per upper (0 - 20 cm and lower (20-40 cm) soil surface.

soil parameters	Depths in cm	Stats	
		Mean	Sd
soil pH (H_20)	0 - 20	7.05	0.24
	20 – 40	7.12	0.87
OC %	0 - 20	1.52	1.08
	20 – 40	1.48	1.07
Total N %	0 - 20	0.11	0.04
	20 – 40	0.12	0.02
P (mg/kg)	0 - 20	9.43	13.92
	20 – 40	19.41	18.72
EC (dS/m)	0 - 20	0.08	0.08
	20 – 40	0.05	0.03
Ca (cmol(+)/kg	0 - 20	8.83	5.59
	20 – 40	9.98	4.16
Mg (cmol(+)/kg	0 - 20	1.62	0.77
	20 – 40	2.09	0.81

Table 2. Mean, and the standard deviation (SD) values for the selected soil parameters in P. hysterophorus L. non-invaded site per upper (0 - 20 cm and lower (20-40 cm) soil surface.

Soil parameters	Depths in cm	Mean	Sd
soil pH (H20)	0 - 20	6.78	0.15
	20-40	6.74	0.32
OC %	0 - 20	1.75	0.70
	20-40	1.74	0.58
Total N %	0 - 20	0.11	0.03
	20-40	0.12	0.01
P (mg/kg)	0 - 20	5.38	3.48
	20-40	4.52	2.44
EC (dS/m)	0 - 20	0.02	0.01
	20-40	0.03	0.02
Ca (cmol(+)/kg	0 - 20	5.68	3.28
	20-40	5.94	5.39
Mg (cmol(+)/kg	0 - 20	2.79	0.92
	20-40	2.59	1.00

A paired samples t-test showed that there is a significant mean difference in the soil pH (p = 0.02 and 0.001) in the upper and lower soil surface respectively (Table 3).

Table 3. Paired t-test mean comparison of the selected soil parameters from *P. hysterophorus* L. in invaded (IN) and non-invaded (NI) sites per soil depth (0-20 cm and 20-40 cm).

Parameters	**depth**	**Mf**	**t-value**	**Df**	**p-value**	**(95%) confidence**		**Significance**
pH	0-20	0.27	2.82	8	**0.02****	0.04878	0.4867	SS
	20-40	0.43	5.01	8	**0.001***	0.2304	0.6229	SS
N	0-20	0.00	-0.05	8	0.94	-0.052	0.0505	NS
	20-40	0.00	0.512	8	0.62	-0.02152	0.03383	NS
C	0-20	-0.23	-0.49	8	0.64	-1.3208	0.85718	NS
	20-40	-0.26	-0.75	8	0.47	-1.0587	0.5387	NS
P	0-20	4.053	0.86	8	0.4132	-6.7766	14.883	NS
	20-40	14.89	2.36	8	**0.046****	0.3178	29.467	SS
EC	0-20	0.060	2.12	8	0.06	-0.00616	0.12771	NS
	20-40	0.033	2.4	8	**0.04****	0.001152	0.06462	SS
Ca	0-20	3.15	1.436	8	0.188	-1.910005	8.21600	NS
	20-40	-2.53	-7.67	8	**0.00*****	-3.3022	-1.7756	SS
Mg	0-20	-1.17	-2.89	8	**0.02*****	-1.0842	0.0865	SS
	20-40	-0.49	-1.97	8	0.085	-1.3180	0.32051	NS

* Mf= mean difference, IN = invaded, NI = non-invaded, SS = statistically significant, NS = statistically not significant.

DISCUSSION

This study intended to compare the means of selected soil chemical properties between invaded and non-invaded sites to examine the variability caused by *P. hysterophorus L*. invasion. The pH of the soil in the invaded site is higher than the pH of non-invaded sites in both soil layers. The higher soil pH in the invaded site could be due to the increased concentration of calcium recorded in the site (Behera and Shukla, 2015) and the lower amount of soil carbon. The soil pH content in the invaded site in both depths was significantly higher than non-invaded site. Similar results were reported by Ojija and Manyanza (2021). Therefore, *P. hysterophorus* invasion affects the soil pH in the study area which in turn will have an effect on solubility and availability of nutrients in the soil.

The soil carbon values in the non-invaded site had more variability than the soil carbon values in the invaded site in both soil layers. However, there was no significant mean difference in invaded and non-invaded sites in both soil layers. Similar results were reported by Etana et al. (2015) and Ojija and Manyanza (2021) who found an insignificant effect of *P. hysterophorus L.* on soil organic carbon. The lower soil organic carbon content in the invaded site may be due to the lower decomposition rate and amount of above-ground biomass of *P. hysterophorus*. The high amount of above-ground biomass together with the higher decomposition rate in the invaded plots may lead to an increase in organic matter and nitrogen content of the soil (Timsina et al., 2011).

The soil total nitrogen values had no variability between invaded and non-invaded sites. As per total nitrogen ratings suggested by Landon (2014), the total soil nitrogen in non-invaded and invaded sites was rated very low and low in the upper soil surface whereas low in the lower soil surface. There was no significant difference ($p < 0.05$) in total soil nitrogen between invaded and non-invaded sites on both soil surfaces. Similarly, Etana et al. (2015) and Ojija and Manyanza (2021) reported non-significant differences in total soil nitrogen in invaded and non-invaded sites.

The available phosphorus content in the non-invaded site was lower than the available phosphorus in an invaded site in both soil layers. This may be because *P. hysterophorus* resulted in a high amount of soil phosphorus released back to the soil surface by decomposition as suggested by Masum et al. (2013). This finding is contrary to that of Ojija and Manyanza (2021) who reported a low amount of phosphorous in the invaded site in 10 cm soil cover. Timsina et al. (2011) reported that soil phosphorus content was higher in the *P. hysterophorus* invaded site at 15 cm soil cover. Similarly, our study revealed that the amount of phosphorus in the invaded site was significantly ($p < 0.05$) higher than the amount of phosphorus in non-invaded sites in 20-40 cm soil cover. The result showed that the invasion of *P. hysterophorus* increased soil phosphorus in the invaded area.

The study showed a significant difference ($p < 0.05$) in soil electric conductivity (EC) between non-invaded and invaded sites. This means that the soil in the invaded site had higher salt content than the soil in non-invaded sites. Hence this invasive species affects soil in the invaded site increasing salinity which in turn affects other living things such as flora and fauna. Electric conductivity is a measure of the contents of salts in the soil and EC of soil is directly affected by the soil's water contents, texture, and proportion of soluble salts (Winegardner, 2019). An EC that is too high in the soil can result in a physiological drought which restricts root water uptake by the plant, even when the substrate is moist (reference?). It results in salt toxicity which burns plant leaves.

The invaded site had higher soil exchangeable calcium content than non-invaded sites in both soil layers which indicated that *P. hysterophorus* had affected the soil calcium in the study site. This maybe because *P. hysterophorus* results in a high amount of soil calcium that it takes from the soil itself (Masum et al., 2013). The higher soil calcium content in the lower soil layer can be related to the nutrient movement to the lower soil surface. There was a significant difference ($p < 0.05$) in soil calcium between invaded and non-invaded sites in the 20-40 cm soil cover. Ojija and Marco Manyanza (2021) found a significant difference between *P. hysterophorus L.* invaded and non-invaded sites in 10 cm soil cover.

Soil-exchangeable magnesium was affected by *P. hysterophorus* in the study site as the exchangeable magnesium content was higher in the non-invaded site than exchangeable magnesium content in the invaded site on both soil surfaces.

CONCLUSION AND RECOMMANDATION

The majority of selected soil fertility parameters showed the trend of enhancement whereas decrease and no change for others because of *P. hysterophorus* L. invasion. But its invasion did not bring adverse impacts on soil based on the current findings in the study area even if reported otherwise by different researchers in different areas. This led to the conclusion that the adverse impact of Parthenium weed on the soil may depend on the duration of its invasion in the given area. *P. hysterophorus L*. may affects plant species either through its allelopathic chemicals discharged or altering the suitable range of soil fertility parameters.

Though *P. hysterophorus* had already been distributed in different parts of the country causing adverse effects on biodiversity, ecosystems, agriculture, food security, and the economy, its impact on parameters like biodiversity (above ground and below) need to be evaluated further. Preventing the spread of this invasive species into more susceptible environments requires an awareness of the distribution of the species and the impacts posed or a threat to a particular ecosystem. Policymakers should commit to developing management strategies that help to interact with local communities in managing this species.

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Appendix 1: The row data values obtained from laboratory analysis for the selected soil parameters.

Site	Depth*	soil pH(H_20)	Organic C%	Total N%	P (mg/kg)	Ca (cmol(+)/k	Mg (cmol(+)/k	EC (dS/m
IN	1	7.02	1.23	0.11	5.32	7.42	1.37	0.06
NI	1	6.53	2.40	0.15	10.14	5.47	2.98	0.04
NI	1	7.03	1.07	0.10	10.14	4.17	3.30	0.02
NI	1	6.72	2.26	0.11	2.99	2.73	3.31	0.03
NI	1	6.76	0.29	0.02	2.74	4.30	3.09	0.02
IN	1	7.36	0.88	0.11	4.40	5.99	2.37	0.05
NI	1	6.73	2.18	0.15	0.17	2.73	3.50	0.02
IN	1	7.27	0.76	0.11	3.74	6.38	1.38	0.04
IN	1	7.24	1.44	0.12	7.48	4.30	0.63	0.05
IN	1	7.15	0.21	0.02	5.57	9.50	2.08	0.06
IN	1	6.71	2.79	0.10	46.12	11.33	2.86	0.23
NI	1	7.02	1.95	0.11	5.90	10.15	2.56	0.02
IN	1	6.65	3.71	0.20	0.00	18.88	2.08	0.24
IN	1	6.97	1.56	0.13	5.32	15.10	1.15	0.03
NI	1	6.72	1.35	0.12	2.66	8.59	2.16	0.02
NI	1	6.70	2.11	0.12	6.98	2.34	0.64	0.02
IN	1	7.08	1.11	0.11	6.98	0.65	0.66	0.04
NI	1	6.83	2.16	0.14	6.73	10.67	3.61	0.05
NI	2	6.86	2.24	0.12	2.66	1.95	2.92	0.03
IN	2	6.96	0.68	0.10	42.71	9.24	3.23	0.11
NI	2	6.06	2.07	0.14	7.73	0.13	3.11	0.03
NI	2	6.82	2.32	0.13	2.08	1.43	4.12	0.02
IN	2	6.85	1.62	0.13	37.97	7.68	2.98	0.14
IN	2	7.18	1.31	0.11	3.57	5.47	2.05	0.04
IN	2	7.48	1.07	0.12	50.27	6.25	1.34	0.03
IN	2	7.16	1.52	0.13	7.23	6.12	1.40	0.04
IN	2	7.11	0.86	0.10	8.48	10.28	2.21	0.05
NI	2	7.01	1.35	0.12	3.82	0.91	2.17	0.02
IN	2	7.30	1.50	0.13	12.30	15.62	1.57	0.04
NI	2	6.45	2.16	0.13	8.14	9.63	2.33	0.06
NI	2	7.01	1.62	0.11	1.83	14.32	1.96	0.03
NI	2	7.06	1.35	0.12	3.16	12.11	1.61	0.02
IN	2	7.22	4.19	0.19	10.64	16.79	1.08	0.03
NI	2	6.81	2.07	0.12	4.49	3.78	1.21	0.02
NI	2	6.63	0.55	0.10	6.81	9.24	3.94	0.00
IN	2	7.29	0.64	0.11	1.58	12.37	3.02	0.04

*1= 0-20 cm soil surface; *2 = 20-40 cm soil surface; *IN = Invaded site; *NI = Non-invaded site.

SOCIOECONOMIC IMPACTS OF ECOHYDROLOGICAL INTERVENTIONS ON THE WETLANDS ALONG THE SOUTHEASTERN SHORE OF LAKE TANA, ETHIOPIA

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ABSTRACT: A study was conducted on Lake Tana shore with the aim of assessing the impacts of ecohydrological intervention on ecosystem services in terms of the socioeconomic contributions for people living along the Lake Tana shore. Three wetlands grouped as protected (intervened site), disturbed (open) and highly disturbed were selected along the Lake Tana shore for the study. The sampling sites were Gumetirs, Gedromesk and Agid Kirgna wetlands where Gedromesk and Agid Kirgna wetlands were selected as reference sites to compare the socioeconomic aspects with the intervened site of Gumetirs wetland. Qualitative and quantitative data on household characteristics, wetland contribution to the local communities and drivers of changes were collected from 90 household heads (HHDs) using a semi-structured questionnaire. Data were analyzed using SPSS software and descriptive statistics. The study revealed that crop production is the major source of livelihood which accounted for 48.9%. About 50% of the respondents were not aware of anthropogenic activities and their negative impacts on the ecosystem. Currently, both Gumetirs and Gedromesk wetlands provide more goods and services contributing to more than 97% of the total value of the wetland goods and services due to water accessibility and availability from the wetland. Wetlands' benefits were associated with the intensive human activities carried out in and around the wetlands, and the level of awareness of the local communities. Ecohydrological intervention provided an immense ecosystem service and also served as a mitigation measure against anthropogenic drivers.

Keywords: Ecosystem services, ecohydrological interventions, human disturbance, Lake Tana, socio-economics

INTRODUCTION

Wetlands play a vital role in providing a wide range of ecosystem services for millions of people mainly living in developing countries (Teferi et al., 2010). Information on wetland ecosystem services, drivers of change and subsequent impacts specific to regions or areas of concern is hence essential for ensuring wise use, conservation and sustainable development (Enserink, 1999). Wetlands are lost or degraded because of What leads to wetland loss or degradation lack of awareness and knowledge on their products, functions,

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attributes and values by human, institutions and policies (Owuor et al., 2012). Human activities within the wetland or in the catchment may accelerate the rate of change or changing the natural processes posing a threat to the wetland's continued existence (Akeem and Lewiska, 2020).

Intensive agriculture with improper land use and exploitative resource management results in significant negative impacts including ecosystem deterioration in the form of water and land degradation, reduction in biological diversity, social and economic impacts, and so on (Ligdi et al., 2012). Consequently, energy flow, nutrient cycle, water cycle, biological process and socio-economic aspects which are provided by the wetlands are greatly disturbed. The degradation of wetlands results in loss of important hydrological and ecological functions. The relevant challenge, therefore, is striking a critical beneficial use of ecosystems for generating livelihoods for local communities without compromising environmental values and uses.

The wetlands in the Lake Tana area are of major significance for the whole region. They provide a myriad of goods and services for humans and animals (Zur Heide, 2012). Lake Tana basin supports different economic activities, and agriculture is the major one. Hence, it has been recognized as a major 'economic corridor' and wetlands along Lake Tana shore support the livelihoods of hundreds of thousands of people in various ways (Stave et al., 2012). However, awareness creation about the importance of wetlands in the Lake Tana Sub-basin is virtually lacking (Mengistu, 2008). A reduction of the buffering role in the ecosystem, the economic benefit and livelihoods they sustain is resulting due to the increasing degradation of wetlands around lake Tana and along the river banks (Zalewski, 2010).

The growing demand to provide evidence of successful implementation of ecohydrology solutions calls for a worldwide ecohydrology demonstration sites in order to validate and quantify the effectiveness of ecohydrological solutions (Cochran, 1977).

Lake Tana has earlier been identified and selected by UNESCO as a representative area to investigate the ecohydrological issues in Ethiopia's Nile basin (Ligdi et al., 2010). Lake Tana demonstration site which is established under UNESCO has focused on finding solutions to water quality, biodiversity, ecosystem

services degradation and resilience issues in Lake Tana, particularly those affected by anthropogenic activities. Gumetirs site was established as one of the ecohydrology demonstration site in 2010 by UNESCO African regional ecohydrology center in Lake Tana shore area.

The ecohydrological system solution demonstration site comprising the integrated activities including implementation of ecohydrology at the buffer zone of the lake to reduce point and non- point sources of pollution, recover degraded ecosystems and soils and optimization of fish-based aquaculture in the Lake Tana shore (Zalewski et al., 2009).

Information regarding the impact of ecohydrological intervention is very crucial to enhance ecosystem services and also to address human impacts on aquatic resources. However, the socioeconomic impacts of ecohydrological intervention of Lake Tana have not yet been addressed and information is lacking in this regard. Thus, this study was conducted with the aim of evaluating and quantifying the ecohydrology interventions impacts related to the socioeconomic attributes of the wetland at the shore of Lake Tana.

MATERIALS AND METHODS

Geographically, Lake Tana is located in the range of 10°58' -12°47 ' N and 36°45' - 38°14' E. It is a source of Blue Nile River and has a total of around 15,000 km^2 drainage areas, of which the lake covers around 3,000 km^2 (Ligdi et al., 2010). The basin drains into the shallow freshwater Lake Tana (Ligdi et al., 2010). The sub-basin can be divided into four distinct physiographic units comprising: the lake water body (including the islands); lower catchments (shorelines and surrounding wetlands); middle catchments (flood plains and gentle hill slopes and upper catchments (low plateau plains, ridges and mountains (Turyahabwe et al., 2013)

Sampling sites

The study was conducted from November 2019 to April 2020 at three sampling sites on the wetlands along the southeastern shore of Lake Tana. The sampling sites were specifically selected based on the reconnaissance field survey which assessed their disturbance extent by anthropogenic activities, the extent and impact of the intervention and accessibility, and availability of goods and services. Both Gedromesk

and Agid Kirgna wetlands were selected as reference sites to compare the socioeconomic aspects with the intervened site of Gumetirs wetland at the lake shore.

Gumetirs wetland is located about 5 km away from Bahir Dar city at Zenzelima Kebele in the southeast direction which is above the outlet of Abay River (Blue Nile River). Geographically, it is located at 11°37'33.4" N and 037°24'41.6" E with an altitude of 1790 m asl. It has an area of less than 5 hectares. This wetland is surrounded by cultivated crops and local residents. It is mainly dominated by *Echinochloa crassipes* and *Cyperus papyrus* plant species.

Gedromesk wetland is located adjacent to Gumetirs study site. This site is mainly surrounded by farmlands and cultivated crops. It is located at $11^0$38'47.7" N and $37^0$25'24.04" E. This wetland is used for grazing and farming land purposes mainly during the dry season. It is mainly covered by *Echinochloa* grass species.

Agid kirgna wetland is surrounded by extended farmlands. It is located in the northeastern direction of Lake Tana at the way of Bahir Dar to Gondar road in Libo Kemkem district. It is geographically located at $12^0$06'5.7" N and $37^0$37'17.1" E. It is situated between Rib and Arno Garno Rivers. This lakeshore is completely covered by water hyacinth. This site is characterized by impacts from agriculture and overgrazing pressure.

Sampling design and data collection

The household survey questionnaire was designed to measure: (I) the benefits obtained from the wetlands, and (II) perception of the local community about wetland benefits and ecohydrological intervention impacts on their livelihood opportunities on the wetland.

For this study, both qualitative and quantitative approach were used to quantify the socioeconomic aspects and assess local people's perception about the impacts of ecohydrological intervention on the livelihood opportunities along the shore of Lake Tana. The primary data were collected through a household survey by using structured questionnaire, interview and observation. The interviewer sometimes tried to use an indirect

approach to address some of the wetland ecosystem benefits and intervention activities to generate qualitative and quantitative data from the respondents.

The survey was undertaken systematically by selecting groups of households living around the lakeshore. Households were selected based on proximity and distance to the lakeshore. The study sites (*Kebeles*) were purposively selected since they are located in the southeastern shore of Lake Tana and have a different degree of human disturbance and benefits at each wetland. A total of 90 respondents were selected for the survey which accounted for 30 respondents from each sampling site following Cochran (1977) method. Cross-sectional interviews of household heads (HHDs) and key informants were conducted in November 2019 using clustered sampling method in the community living within a 3-km radius of each wetland (Tariku et al., 2014; Tewabe, 2014).

Data analysis

SPSS version 20.0 software was employed to analyze the socioeconomic data collected through structured questionnaires. The data were analyzed using descriptive statistics (mean, percentage, and frequency distribution) and Chi-square test.

RESULTS

Demographic characteristics of sampled household

The findings from the structured questionnaire indicated that the majority of the respondents who participated in the study were male-headed accounting for 65.6%, while the female-headed accounted for 34.4% (Table 1). On the other hand, the mean age of respondent age was 40 with a minimum of 25 and a maximum of 61 years old. Regarding the level of education, the result showed that 58.9% of the respondents which accounted for half of the participants did not get access to formal education. On the other hand, almost three fourth of the respondents (84.4%) got married and the mean family size of the respondents was five per each family, while. 92% of the respondents were farmers compared to government employed and self-employed respondents.

Table 1. Socio-economic characteristics of the sampled households.

Socioeconomic characteristics	Description	Percentage
Gender	Male	65.6%
	Female	34.4%
Age	Mean: 40	
	Range: 25-61	
Level of education	No education or basic education	58.9%
	Primary education	35.6 %
	Secondary education	4.4%
	College or University	1.1%
Social status	Single	14.4%
	Married	84.4%
	Divorced	1.1%
Occupation	Government employed	1.1%
	Self-employed	6.7%
	Farmer	92.2%
Family size	Mean: 5	
	Range: 1-8	

Sources of livelihood of sampled household in selected kebeles

Five major sources of livelihood were identified (Table 2). On average, crop was the mainstay of livelihoods for the majority of the households which accounted for 48.9% of total respondents of the three sampling sites (kebeles). It is followed by crop, livestock (21.1%) and fodder, fruit and vegetable sales (21.1%), which are the other sources of livelihood for the local people. However, the smallest source of livelihood was rent land, which only accounted for 1.1% among the other sources of livelihoods. The inferential statistics test indicated that there was a statistically significant difference in sources of livelihood across the sites ($X2$ (12, $N = 90$) = 34.304, $p = 0.001$.

Table 2. Sources of livelihood of the sampled household heads.

Sources of livelihood	Sample sites			Mean	Std. Error	Frequency	Percent (%)	Sig.
	Gt	Gm	Ak					
Crop	9	12	23	14.7	4.3	44	48.9	0.001
Forestry	1	2	0	1	0.6	3	3.4	
Livestock	4	9	6	6.3	1.5	19	21.1	
Rent land	0	1	0	0.3	0.3	1	1.1	
Agricultural wage	0	1	1	0.7	0.3	2	2.2	
Fodder, fruits and vegetable sales	14	5	0	6.3	4.1	19	21.1	
Small scale business	2	0	0	0.7	0.7	2	2.2	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

Number of people that depends on the wetland resources and degree of dependency

The results revealed that 72.2% of 1 up to 5 family sizes of the respondents was depending on the wetland resources. On the other hand, the degree of dependency of most participants (58.9%) was partial and those who fully dependent on wetland resources was found to be 36.7% (Table 3). There was no significant difference in the number of dependent families and degree of dependency on the wetlands, X2 (2, N = 90) = 1.440, p = 0.487 and, X2 (4, N = 90) = 2.853, p = 0.583, respectively.

Table 3. Number of dependents and degree of dependency of the sampled household heads.

	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Number of family dependent on the wetland								
1-5	20	24	21	21.7	1.2	65	72.2	
5-10	10	6	9	8.3	1.2	25	27.8	
Degree of dependency								
Fully dependent	8	14	11	11	1.73	33	36.7	0.583
Partial dependent	20	15	18	17.7	1.45	53	58.9	
Independent	2	1	1	1.3	0.33	4	4.4	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

Overall trends of benefits and concern of biodiversity in the wetlands

The respondents were asked their opinion on the overall trend of benefits in the last five years and their concern about wetland biodiversity and their contribution in maintaining the healthy functioning of the ecosystem. The respondents were asked their opinion and awareness of wetland degradation. Among the three study sites, the overall trends of benefits from the wetland of Gumetirs site increased compared to Gedromesk and Agid kirgna in the last five years. Despite the overall trends of wetland benefits increased in Gumetirs site, 62.3% of the respondent stated that wetland benefits across the site were decreased. On the other side, the overall concern of the community about biodiversity was moderate (64.4%). However, the trends of benefits provided by the Agid kirgna wetland were completely decreased in the last five years (Table 4). Additionally, the respondents were asked their attitude towards wetland degradation and its cause and consequence. As a result, half (51%) of the respondents had moderate awareness about wetland degradation. The majority of the respondents in Gumetirs site had good awareness compared to the other two wetland sites. Statistically, there was a significant difference in the overall trends of benefits, $X2$ (4, N =90) = 46.542, p = 0.001, and concerns of biodiversity, $X2$ (4, N =90) = 23.203, p = 0.002 and awareness of wetland degradation, $X2$ (4, N =90) = 27.952, p = 0.003 among the sampling sites.

Protection status of wetlands

This section asses the protection extent of the wetlands. The finding revealed that majority of the respondents (25.6%) agreed to the fact that overgrazing, free grazing and pollution are not prohibited in the wetland (Table 5). This is especially observed in the Agid kirgna site which accounted for 56.5% compared to the remaining sites. Generally, Gumetirs site was protected properly than the other two wetlands in which farming and hunting practices are not allowed in the wetland. There was a significant difference in the protection status of the wetlands across the sampling sites, $X2$ (16, N =90) = 90.723, p = 0.003

Table 4. Overall trends, awareness and concerns of wetland benefits, degradation and biodiversity of the sampled households.

	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Overall trends of benefits in the last five years								
No change	10	2	0	4	3.06	12	13.3	0.001
Decreased	5	21	30	18.7	7.31	56	62.3	
Increased	15	7	0	7.3	4.33	22	24.4	
Overall concern of local people for biodiversity								
Highly concerned	14	6	2	7.3	3.53	22	24.4	0.002
Moderately concerned	14	24	20	19.3	2.91	58	64.4	
Unconcerned	2	0	8	3.3	2.4	10	11.1	
Awareness of local people about wetland degradation								
Largely aware	15	7	0	7.33	4.33	22	24.4	0.003
Moderately aware	15	13	23	17	3.06	51	56.7	
Largely unaware	0	10	7	5.67	2.96	17	18.9	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

Table 5. Protection status of wetlands of the sampled households.

	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Protection status of the wetland								
Fishing prohibited or regulated	2	1	0	1	0.58	3	3.3	
Biosphere reserve	1	0	0	0.3	0.33	1	1.1	
Farming is prohibited	10	0	0	3.3	3.33	10	11.1	0.003
Hunting prohibited	3	0	0	1	1	3	3.3	
Over grazing, free grazing and pollution prohibited	14	0	0	4.7	4.67	14	15.6	
Not yet protected	0	5	6	3.7	1.86	11	12.2	
Over grazing, free grazing and pollution are not prohibited	0	10	13	7.7	3.93	23	25.6	
Farming is not prohibited	0	7	8	5	2.52	15	16.7	
Fishing is not prohibited	0	7	3	3.33	2.03	10	11.1	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

Major uses, anthropogenic activities and use of vegetation cover of wetlands

The findings revealed that the majority of the respondents agreed that grazing or fodder for livestock and water supply for irrigation purpose were the two major uses of the wetland across the sampling sites (Table 6). Moreover, cultivation of crops including vegetables and fruits were the third major use of wetland for the sampled households.

Table 6. Major uses, anthropogenic activities and uses of vegetation cover of the wetland of the sampled households.

	Sampling site			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Major uses of the wetland to the local people								
Grazing or fodder for livestock	10	11	12	11	0.58	33	36.7	0.001
Reed gathering	2	3	0	1.67	0.88	5	5.6	
Cultivation of crops including vegetables and fruits	6	2	1	3	1.53	9	10	
Water supply for irrigation	10	11	3	8	2.52	24	26.7	
Fishing and culturing	2	3	3	2.67	0.33	8	8.9	
Sand mining	0	0	3	1	1	3	3.3	
Source of drinking water	0	0	8	2.67	2.67	8	8.9	
Anthropogenic activities and impacts								
Yes	24	15	12	17	3.61	45	50	0.003
No	6	15	18	13	3.61	45	50	
Uses of vegetation cover for lake health								
Aware	18	13	13	14.67	1.67	44	48.9	0.329
Not aware	12	17	17	15.33	1.67	46	51.1	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

Among the study sites, Agid kirgna site was highly exposed to overgrazing. About 50% of the respondents understood those anthropogenic activities and their negative impacts on the normal functioning of the ecosystem. Conversely, half of the respondents (50%) were not aware of anthropogenic activities and their

negative impacts on the normal functioning of the ecosystem health. On the other side, 48.9% the respondents understood the importance of vegetation cover for both ecosystem health but more than half (51.1%) of the respondents were not aware on the use of vegetation cover for ecosystem health. There was a significant difference in the major uses of wetland across the wetlands, X2 (12, N =90) = 34.648, p = 0.001 and awareness of anthropogenic activities and its impact, X2 (2, N =90) = 17.867, p = 0.003. However, there was no significant difference among the sampled sites in the use of vegetation cover for ecosystem health, X2 (2, N =90) = 2.223, p = 0.329.

Income contribution of wetlands for the sampled households

Livelihood sources such as fish, grass, fruits and vegetables, Cyprus papyrus reed, milk, biogas, fattening and compost were significant ecosystem services provided by the wetland (Table 7). The result showed that the majority of the respondents (31.1%) gained 1-10kg fish product per year. Comparatively, more fish products were obtained in Gumetirs site compared to Gedromesk and Agid kirgna. However, 48.9% of the respondents did not get fish throughout the year from the wetland. There was a significant difference across the site in fish products, X2 (8, N =90) = 28.829, p = 0.002. Similarly, a wetland in Gumetirs site provided more grass production than the other two reference sites. There was a significant difference, X2 (10, N =90) = 65.524, p = 0.001 in grass production among the sampling sites. On the other hand, results showed that wetlands were valued as major cultivation site of vegetables and fruits even though more yield was obtained in both Gumetirs and Gedromesk sites with an amount of between 1500- 2500kg per year. However, fruit and vegetable productions not much produced in Gedromesk site but nothing in Agid kirgna sampling site. Statistically, there was a significant difference, X2 (8, N =90) = 84.586, p = 0.001 in fruits and vegetation production among sampling sites.

Table 7. Types of income gained by the sampled household heads per year

	Sample site			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Products obtained from the wetlands per year								
Fish								0.002
1-10 kg	17	9	2	9.33	4.33	28	31.1	
10-20 kg	3	5	1	3	1.15	9	10	
20-30 kg	4	2	2	2.67	0.67	8	8.9	
30-400 kg	0	0	1	0.33	0.33	1	1.1	
nothing	6	14	24	14.67	5.21	44	48.9	
Grass								
100-150 ton	3	0	0	1	1	3	3.3	
150-250 ton	7	0	0	2.33	2.33	7	7.7	
250-300 ton	4	2	0	2	1.15	6	6.6	0.001
300-350 ton	7	9	0	5.33	2.73	16	17.8	
350-400 ton	7	6	0	4.33	2.19	13	14.4	
nothing	2	13	30	15	8.14	45	50	
Fruits and vegetables								
Below 500 kg				4	4.33		13.3	
500-1500 kg	3	10	0	4.33	1	13	14.4	
1500- 2500 kg	12	3	0	5	3.84	15	16.7	0.001
above 2500 kg	11	3	0	4.67	3.38	14	15.6	
nothing	1	5	30	12	8.39	36	40.0	
***Cyperus papyrus* reed**								
50-100 ton				3.33	2.03		11.1	
100-150 ton	3	0	0	1	1	3	3.3	
150-200 ton	5	1	0	2	1.53	6	6.7	0.002
200-250 ton	9	0	0	3	3	9	10	
above 250 ton	7	0	0	2.33	2.33	7	7.8	
nothing	3	22	30	18.33	8.01	55	61.1	
Milk								
500 L	1	2	13	5.33	3.84	16	17.8	
500L-1000 L	1	3	0	1.33	0.88	4	4.4	
1000L-1500 L	1	8	0	3	2.52	9	10	0.003
above 1500 L	16	3	0	6.33	4.91	19	21.1	
nothing	11	14	17	14	1.73	42	46.7	
Biogas								
1000-2000 Birr saving	6	1	0	2.33	1.86	7	7.8	
2000-3000 Birr saving	3	0	0	1	1	3	3.3	
3000-5000 Birr saving	4	2	0	2	1.15	6	6.7	0.002
above 5000 Birr saving	3	1	0	1.33	0.88	4	4.4	
nothing	14	26	30	23.33	4.81	70	77.8	
Fattening								
1500-2500 Birr	0	2	0	0.67	0.67	5	5.6	
2500-3500 Birr	1	4	0	1.67	1.2	2	2.2	0.001
500-1500 Birr	2	0	0	0.67	0.67	2	2.2	
more than 4500 Birr	20	8	0	9.33	5.81	28	31.1	
nothing	7	16	30	17.67	6.69	53	58.9	
Compost								
500-1000 Birr		1	0	1.33	0.88	4	4.4	
1000-2000 Birr	1	2	0	1	0.58	3	3.3	0.004
more than 2000 Birr	21	10	0	10.33	6.06	31	34.4	
nothing	5	17	30	17.33	7.22	52	57.8	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

The majority of households obtained Cyprus papyrus reed mainly from Gumetirs site by either selling raw papyrus materials or after value addition through mat making. More production was obtained from the Gumetirs wetland which totally accounted for 38.9% by many households. Despite more respondents have got papyrus from Gumetirs wetland and Gedromesk wetland, there was nothing obtained papyrus reed products in Agid kirgna wetland which accounted for 61.1%. There was a significant difference, X2 (10, N =90) = 73.382, p = 0.002 in Cyprus papyrus production across the study sites. Similarly, products such as milk, biogas, fattening and compost were mainly obtained from Gumetirs wetland which accounted for nearly 90% of all product types compared to other sites. According to the result from chi-square test, there was a strong evidence of significant difference in milk products, X2 (8, N =90) = 56.919, p = 0.003; biogas, X2 (8, N =90) = 28.300, p = 0.002; fattening, X2 (8, N =90) = 50.122, p = 0.001 and compost, X2 (6, N =90) = 44.893, p = 0.004 products across the sample sites.

Among the alternative questions under the changes in the wetland area, 66.67% of the respondents answered the prominent cause of change in wetland area was recession farming and conversion to agricultural land especially in Gedromesk site and Agid kirgna site (Table 8). Moreover, there was a significant difference, X2 (4, N =90) = 73.257, p = 0.001 in changes in wetland area across sample sites. On the other side, the majority of the respondents identified the building of a dam (48.9% respondents) and change in land use (41.11% respondents), as the cause of change in water regime. There was a significant difference in change in water regime, X2 (4, N =90) = 13.518, p = 0.003 and water quality, X2 (6, N =90) = 86.514, p = 0.002. Nearly, 60% of the respondents answered that exploitation was mainly observed in Gedromesk site and Agid kirgna sites due to overgrazing of the wetland vegetation in and around the wetland area. On the other hand, 33.33% of the respondents agreed that the main alien species was water hyacinth, especially in Agid kirgna. Moreover, there was a significant difference, X2 (4, N =90) = 61.181, p = 0.003 in the invasion of alien species across sampling sites in the wetlands.

From the interviewed respondents, 22.22% of them agreed that prohibition of free grazing and recession farming as a management strategy. There was a significant difference, X2 (8, N =90) = 60.238, p = 0.001 in the management strategies which were recommended by sampled respondents for each study site.

Table 8. Changes in area, water regime and quality, exploitation, alien species, and management strategies of the wetlands.

	Sampling sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Changes in wetland area								
Land conversion to urban areas	2	0	0	0.67	0.67	2	2.22	0.001
Conversion into agricultural land	2	28	30	20.00	9.02	60	66.67	
No change	26	2	0	9.33	8.35	28	31.11	
Land conversion to industrial area	0	0	0	0	0	0	0	
Changes in the water regime								
Dam	16	14	12	14	1.15	44	48.9	0.003
Drainage	0	0	6	2.00	2.00	6	6.66	
Irrigation	13	15	12	13.33	0.88	40	44.44	
Change in water quality								
Nutrient enrichment	0	1	0	0.33	0.33	1	1.11	0.002
Fertilizer/Pesticide/Herbicide	2	8	14	8.00	3.46	24	26.67	
Changes in land use	0	21	16	12.33	6.33	37	41.11	
No change	28	0	0	9.33	9.33	28	31.11	
Exploitation								
Overfishing	13	10	0	7.67	3.93	23	25.56	0.001
Overhunting	14	0	0	4.67	4.67	14	15.56	
Overgrazing	3	20	30	17.67	7.88	53	58.89	
Alien species								
Water hyacinth	0	0	30	10.00	10.00	30	33.33	0.003
Other invasive weeds	2	9	0	3.67	2.73	11	12.22	
No alien species	28	21	0	16.33	8.41	49	54.44	
Management strategies								
Vegetation restoration	4	5	10	6.33	1.86	19	21.11	0.001
Management of hunting	13	3	0	5.33	3.93	16	17.78	
Management of fishing	13	2	0	5.00	4.04	15	16.67	
Prohibit free grazing	0	10	10	6.67	3.33	20	22.22	
Prohibit recession farming	0	10	10	6.67	3.33	20	22.22	

Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna

DISCUSSIONS

The fertile shores of Lake Tana have provided provisioning, structural, regulating and cultural values for the local communities for thousands of years.

There are huge differences among the wetlands studied. Gedromesk and Agid kirgna sites are highly affected by agricultural activities and overgrazing. Their buffer zone vegetation was highly degraded by overgrazing, drainage and recession agriculture mainly during the dry season. Agid kirgna wetland is devoid of buffer vegetation. Gedromesk wetland is relatively covered by Echinochloa plant species. However, Gumetirs wetland is dominantly covered by Echinochloa meadow and Cyprus papyrus reed.

In the study sites, the majority of the household sources of incomes are mainly originated from within and around the wetlands directly or indirectly. These include crop farming, forestry production, livestock rearing, and land renting, and growing of fruits, vegetables, and grass and papyrus reeds production. On the other hand, crop production was found to be the most source of livelihood for the local communities in the study sites. This result showed that crop production is the common agricultural practice to generate income for the local community. This is because wetlands have fertile soils as a result of regular sediment deposition during flood events (Verhoeven and Setter, 2010). The local community perceives crop production has higher income compared to other livelihood types. Due to this reason, households demand more farming land to get more products. The local people need to expand the crop farming area beyond their previous territory of land. Furthermore, this suggests that local households are less likely to depend on other sources of livelihoods and more likely depend on crop production mainly the cultivated one. As a result, the local community increases pressure to nearest lake shore areas to cultivate more crops. It was evidenced that degradation of water quality and biodiversity increases when they apply fertilizer and pesticide chemicals to crop farming. With regards to site specific, fruit, vegetable and grass for fodder were produced more in Gumetirs sampling site. The sources of livelihoods mainly affect the number of families that depend on the wetlands. The result revealed that the number of a family that depends on the wetland ranged from 1-5 person per family.

On the other hand, on average, 62.3% of the respondents agreed that the overall trends of benefits in the last five years decreased even though Gumetirs wetland benefits increased. The majority of the local households

lack well understanding and adopting sustainable use of wetland resources. On average, the majority of the respondents are not concerned highly about those anthropogenic activities and impacts. Lack of adequate knowledge and awareness about wetlands results in wetland deterioration from overexploitation and thereby affects their sustainable existence (Tewabe, 2014). The low level of community awareness concerning wetlands and their benefits also accelerates the loss of wetlands in the country (Unbushe, 2013).

The majority of the respondents in Gumetirs sites are highly concerned and largely aware of biodiversity and the impacts of anthropogenic activities. This implies that Gumetirs site provides better ecosystem services compared to the other two reference sites. This is most probably due to the awareness raising effort together with other intervention activities at the lakeshore of the wetland. On the other hand, the local households in Gumetirs site have better concern and awareness of biodiversity and anthropogenic activities impacts on the ecosystem than the other two sites. Public awareness creation is one of the most important ways to conserve wetlands and enable the public to be more environmentally conscious (Mohammed, 2015). For successful conservation and management, the participating local communities should be fully aware of the importance of wetlands as part of water cycles, as well as the nature and effects of human impacts (Williams, 2002). However, awareness creation about the importance of wetlands in the Lake Tana Sub-basin is virtually lacking (Mengistu, 2008).

Moreover, the Gumetirs site was found in good protection status as compared to the other wetlands. This is due to community participation and coordination with integrated water resource management organizations on using the water and land resources sustainably, which is in line to the report by Andrade and Rhodes (2012) which revealed that the higher the level of community participation, the higher their compliance to the resource conservation; community inclusion is a must for long-term conservation.

The protection status of the wetlands indicates that many respondents agreed that free grazing and pollution are not prohibited in Gedromesk and Agid kirgna wetlands. This in turn easily degrades and minimizes the benefits provided by wetlands. Comparatively, free grazing, overgrazing and pollution is strictly prohibited

in Gumetirs site. As a result of proper protection in Gumetirs site, wetland benefits are sustainable throughout the year.

On average, across the site, grazing and crop production are the major use of the wetlands. The result showed that in Gumetirs site grass production, vegetable and fruit, chat (*Catha edulis*) production and reed gathering were the major uses of the wetland. Many of these products demand more water during the dry season. Comparatively, there is less water abstraction in Gedromesk and Agid kirgna sites because of few water demanding products around the wetlands.

Half of the respondents (50%) understand that anthropogenic activities have great impacts on the sustainable use of wetland benefits and overall ecosystem health.

On average 51.1%, majority of the respondents positively recognize that vegetation cover is important. Most respondents perceived that vegetation cover serves as fodder for their livestock. But few of the respondents recognize that vegetation cover is important for fish as a source of food, and breeding ground, nutrient uptake, stabilize water temperature as well as to keep water quality and quantity. This finding is somewhat similar to Wondie (2018). However, about 50% of respondents were not aware of the use of vegetation cover. As a result, the vegetation cover within and around the lakeshore may be prone to continuous degradation of macrophytes.

It is good to note that much of the wetland resources were obtained from the Gumetirs. Wetland benefits such as fish, vegetables, fruits, grass, papyrus reed, milk, biogas, fattening, and compost productions are some of the wetland benefits used by the local households.

Both Gumetirs and Gedromesk currently provide more goods and services such as cultivation of Chat, Cabbage, Mango and Avocado, grass (fodder) production and milk production predominantly provided by Gumetirs wetland contributing to more than 97% of the total value of the wetland goods and services for the local people.

More fruits and vegetables were obtained in Gumetirs wetland due to water accessibility and availability from the wetland. This implies that the community who lives around this wetland has multiple livelihoods. Hence, well-managed wetlands are among the most productive ecosystems which provide the opportunity for sustainable development, helping to meet the needs for improved living standards in developing countries like Ethiopia (Tafa, 2018).

Furthermore, the importance of this study point towards the change in the wetland area, water regime and quality, extent of exploitation, the invasive species invasion condition, and the management strategies. On average, 66.67 % of respondents agreed that the main causes of change in wetland's area are the conversion of wetland into agricultural land through recession farming. Due to this reason, the area of land has been shrinking from time to time. Degradation and loss of wetland is now a big threat to the benefits provided by the wetland for the local community. Similarly, according to Minale and Kameswara (2011) reported that most of the wetlands in the catchment have been continuously declined, while the farming lands and settlement areas have been increasing.

In the studied sites, the change in wetland regime could be caused by the building of a dam, drainage of water to expand agricultural land, channelization, and abstraction of water for irrigation purposes. It increases and decreases the water level depending on the season. Wetland water level decreases during the dry season. In this case, the expansion of recession farming also increases. The change in water quality in the wetland is caused by both changes in land use and nutrient (fertilizer, pesticide, and herbicide) runoff from agricultural fields. Nutrient runoff might be mainly caused by the severe upland erosion in the catchment. The discharges of surplus nutrients in the upper catchment easily enter into the wetland through flooding. The nutrients in the lake without vegetation cover causes eutrophication which affects living things in the water. Additionally, a high load of sediment affects the growth and regeneration of macrophytes.

According to the respondents, the main cause of exploitation in the wetlands is overgrazing. Grazing pressure has damaged wetlands especially in Gedromesk and Agid kirgna sites quite badly. This, in turn,

has an impact on the vegetation cover and enhances eutrophication due to livestock's wastes. When grazing continuous livestock trample and compact the soil destroys natural vegetation, affects the infiltration capacity of the soil, and erode drainage channels leading to gullies and water outflow (McKee, 2007).

Weed infestation in wetlands is a big problem particularly on the northeast shore of Lake Tana. Water hyacinth is the most invasive and destructive weed found in Agid kirgna. As a result of complete coverage of water hyacinth, the previous benefits provided by Agid kiregna wetland for the local community are being impaired. The overall ecosystem health and benefits are under risk. Nearly, 60% of the respondents agreed that overexploitation was mainly observed in Gedromesk and Agid kirgna sites. As a result, many lakeshore areas of macrophytes were replaced by invasive weeds such as water hyacinth especially in Agid kirgna site (33.33%). Invasive species are one of the major threats to biodiversity in the world due to their effect on the homogenization of the ecosystems (Enserink, 1999).

The result indicates that on average the majority of the respondents share that the most management strategies to conserve and safeguard the wetland ecosystem and benefits are the prohibition of overgrazing and recession farming. The intensive cultivation and free grazing activities in Shesher and Welala wetlands, for example, resulted in drastic shrinkage of their coverage (Atnafu et al., 2011). Recession agriculture is still considered as an advanced mode of development for many people.

Generally, the survey result indicates that the majority of the sampling sites are mainly affected by the changes in the area, water quality and quantity, and the invasion of invasive species. As a result, goods and services provided by the wetlands have decreased and the wetland faces several challenges as a result of human activities on the wetlands. Activities such as recession farming, crop cultivation, free grazing, intensive agricultural land use, nutrient runoff from the upland catchment, unregulated fishing, and illegal hunting are some of the major causes of wetland degradation.

According to the respondents, Gumetirs site was found in a good ecological condition compared to the other two wetlands. In Gumetirs site, free grazing is not allowed rather cut and carries of Echinochloa grass species and Cyprus papyrus reeds are utilized in a sustainable and manageable way.

CONCLUSION AND RECOMMENDATIONS

Overall, the socioeconomic survey result confirmed that the ranges of wetland benefits significantly related to the degree of disturbance and awareness level of the local community. As a result of human disturbances, wetland benefits varied among sites along the wetlands. This study confirmed that low disturbed wetland supports more socioeconomic benefits than moderately and highly disturbed wetlands. All but the protected (intervened) wetlands were found to be degraded associated with the degree of human disturbances. The result of this study also assured that the presence of better ecosystem services indicate that the wetland is found in good conditions. As recommendation, emphasis should be given to the factors which may lead to the degradation of wetland benefits within and its catchment especially with regards to recession farming, overharvesting, overgrazing and invasion of water hyacinth.

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LIVESTOCK PREDATION AROUND GUNA MOUNTAIN COMMUNITY CONSERVATION AREA, AMHARA REGION, ETHIOPIA

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ABSTRACT: Livestock predation by carnivores is an increasing conservation challenge for wildlife conservation in many developing countries. In this study, the livestock predation by predators in Guna Mountain Community Conservation Area (GMCCA) between September 2019 and August 2022 was determined. Data were collected from 287 households, spread across 14 villages on number of livestock predated, predators responsible for the kills and season of predation. The major predators and their contribution were, African wolf (*Canis lupus lupaster*), 75.7%), Spotted hyena (*Crocuta crocuta* (10.8%), Leopard (*Panthera pardus* (7.9%) and Serval cat (*Leptailurus serval* (5.6%). The most serious predator was African wolf, which mainly predated on sheep (88.2 %, N= 1796). Sheep were the dominant livestock affected by predators. The larger proportion of the livestock depredation occurred during the rainy season (76.69 %, N= 1819). The overall economic loss by predator attacks was estimated to be about 136 USD per household per year. African wolf contributed the largest proportion of the economic loss (70.83%). Livestock kills were not reported during the night from the underground shelter which was practiced by 89.2% of the households. The predation rate decreases with increasing distance from the boundaries of the GMCCA, and villages with the closest distance to the protected area lost more livestock. In prevention of the African wolf predation, developing the grazing land management will greatly minimize the economic loss. The underground shelter of livestock was found to be effective technique which could be implemented in other highlands of Ethiopia as well.

Keywords: Carnivore; Economic loss, Human carnivore conflict; Livestock depredation, Predation

INTRODUCTION

Humans and wildlife have coexisted for centuries. The trend however is disrupted following the exponential growth of human population. As human population increases, more and more land which was previously inhabited by wildlife was taken by human settlement and agriculture which in turn intensify the human wildlife conflict (Kolowski and Holekamp, 2006). While livestock predation by carnivores is a conservation challenge at global scale, its economic impact is prominent in subsistent agropastoral communities in developing countries (Ogada et al., 2003; Woodroffe et al., 2005). The larger proportion of East African

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countries which are rich in biodiversity are mainly subsistent farmers combining livestock husbandry and farming (Salami et al., 2010). In the Ethiopian economy, agriculture is the largest sector accounting for over 50% of GDP and employing over 85% of the Labour force (Alemu et al., 2003).

The average income of Ethiopia, Kenya and Tanzania for instance is less than $5 per person per day (Andinet et al., 2015). A single sheep loss in such countries is loss of about $150 which makes the livestock predation costly and potentially affecting their survival (Narisha, 2015).

To safeguard the survival of wildlife species in the face of increasing human population, protected areas are established across African countries most of which are too small for carnivores which have large home range (Ogada et al., 2003; Patterson et al., 2004). Most protected areas do not have enough buffer zone from the livestock grazing land which makes carnivores to get in contact with livestock more frequently (Hayward and Kerley, 2005; Soh et al., 2014). The natural prey of the carnivores also declined as a result of anthropogenic reasons, which forces predator carnivore prey on livestock for their survival.

For sustainable biodiversity conservation effort, monitoring wildlife species and minimizing the human wildlife conflict, in particular livestock depredation is crucial. As many of the Ethiopian highlands, GMCCA is also home for several carnivore species that potentially predate on livestock. Regardless of this however, no study was carried out on the livestock predation prevalence in the area. Therefore, this study aims to determine the livestock depredation rate, its economic consequences and mitigation methods used by the local community in GMCCA.

MATERIALS AND METHODS

Study area

Guna Mountain Community Conservation area extends from $11^0$39’48.09’’ to $11^0$45’31.61’’E longitude and from $38^0$10’19.59’’ to $38^0$16’34.63’’N latitude. It is located in South Gondar zone; surrounded by three Woredas including Estie, Lay Gaynt and Guna Begemider, with 11 adjacent kebeles namely Arga-didim, Mokish and Soras from Guna begemider; Dera-Kefoye, Guna-Gedeba, Akabit and Titira-damot from Lay

Gaynt and Liwaye, Wuchiba-sanqua, Elet-dibana and Dat-Georgis from Estie Woreda. The community conservation area is located at a distance of 20 km from Debre Tabor in the south eastern direction and at a distance of 30km from Nefas Mewcha in the western direction (Figure 1). The elevation of the conservation area ranges from 3,441 to 4,113 masl and its total area is about 4615 hectares.

The major occupation in the selected woredas is agriculture and the main agricultural crops cultivated in the woreda include potato, wheat, barley and bean. Also, cattle, sheep, poultry and horses are the major livestock kept by the farmers (personal communication).

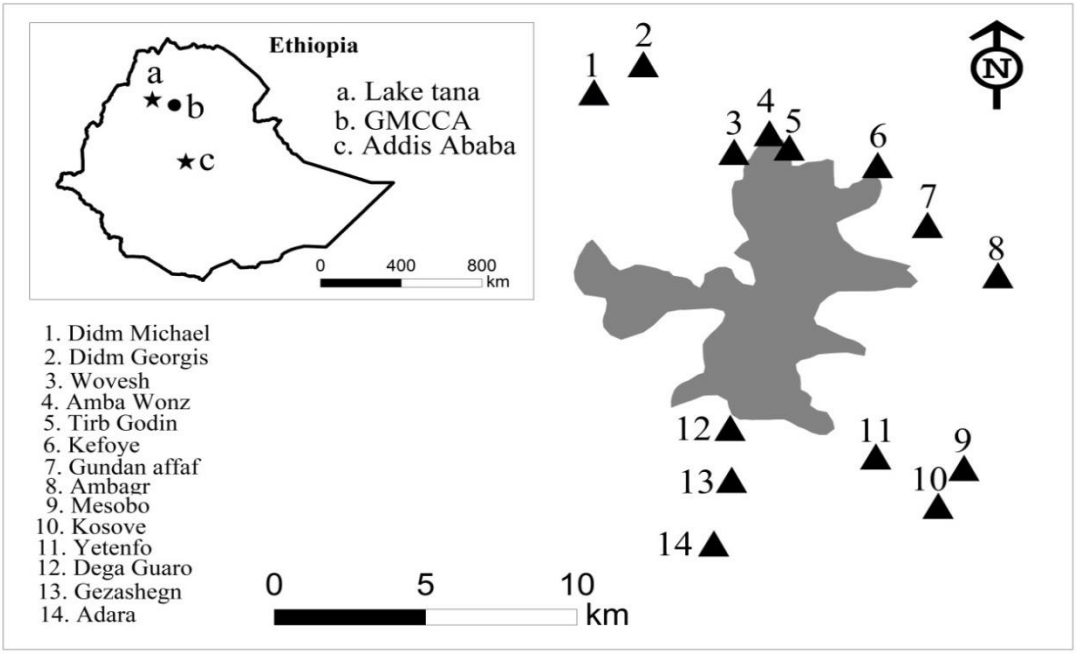

Figure 1. Map of Guna Mountain Community Conservation Areas including its surrounding villages.

The study was conducted between December 2021 and August 2022. All the 14 villages within 10 km distance from the buffer zone were mapped from GPS coordinate collected during the study. The villages were categorized in three zones on bases of their distance from the buffer zone of the protected area, very close (0 - 1 km), medium (1 –3 km) and far (> 4km) (Table 1) once their distance from the buffer zone is estimated from Arc Map 10.4.

Table 1. Villages found around GMCCA, their distance from the periphery, total number of households and sampled households from each village.

Distance	Villages	Total number of households	Sampled households
0 - 1 km	Amba Wonz, Tirb Godin, Dega Guaro, Kefoye and Wovesh	2032	101
1-3 km	Yetenfo, Gezashegn and Gundan Afaf	955	47
> 4 km	Didm Michael, Didm Georgis, Adara, Kosoye, Mesobo and Ambagr	2787	138
Total		5,774	287

The total number of households that was sampled in each village were determined using Kothari (1999). According to Kothari a sampling range of between 5-20% of total population in descriptive research is acceptable because it fulfills the requirement of efficiency, representativeness, reliability and flexibility. From the total households of 5,774, a total of 287 households were selected for semi structured interview randomly. The interview started from one end of the village and continued by skipping the next immediate household until about 5% of the households in each village was covered. During the questionnaire survey, each of the household was asked on the number and type of livestock they own, number and type of livestock predated between September 2019 and August 2022, responsible predator, how they identify the predator, season when the livestock was predated (rainy or dry), time of predation (day or night), where the livestock predation had occurred (during grazing or in shelter) and methods used to protect livestock predation.

The predator responsible for each of the killings reported by the local community was identified by the characteristic of the kill. For instance, leopards kill their prey with a bite to the throat; in contrast, spotted hyenas usually attack the base of stomach. African wolf attack livestock while they were grazing in the field, and the bite on the livestock is on a random part of its body.

Data analysis

The differences in predation among the villages were compared using one-way ANOVA using Statistical Package for Social Sciences (SPSS) version 23. Pearson Correlation was used to test the relation between

distance of study village from edge of protected area and the occurred loss of domestic animal. Chi- square test was used to determine whether there is a relationship between the number of livestock killed per predator, season and time of predation. To estimate the economic loss from the livestock predation, the values of livestock loss was estimated based on the local market averaging 20 animals from each livestock, and convert the value to USD using the exchange rate of 1 USD to 54.3 ETB (official exchange rate for the year 2022).

The total loss was determined as a monetary value, losses due to predation can be calculated as:

$C = L\ x\ P$ where,

C= stands for total direct losses incurred by livestock producers,

L= total number of livestock lost due to predation per year,

P= Monetary value allocated per head to livestock lost

RESULTS

Abundance of livestock

A total of 4546 domestic animals were reported in the study area including cattle, sheep, goat, horse, mule, donkey, poultry and dog (Table 2), of which 2,372 domestic animals were reported to be predated by African wolf (75.7%), Spotted hyena (10.8%), Leopard (7.9%) and Serval cat (5.6%) during the study period.

Table 2. Livestock predation by wild carnivores relative to the abundance of livestock in 2022 around GMCCA.

Domestic animal	No.	No. predated	% predated
Cattle	861	0	0
Sheep	1841	858	67.1
Goat	111	72	5.6
Horse	409	67	5.2
Mule	296	2	0.2
Donkey	106	5	0.4
Poultry	658	274	21.4
Dog	264	36	2.8
Total	4546	1278	100

The most serious predator, African wolf, mainly predated on sheep (88.2 %, N= 1796). Hyena predate on diverse livestock types mainly on horse (39.6%), sheep (29.8%), mule (1.96%) and donkey (1.96%), N= 255). Leopard predates exclusively on goat (45.4%) and sheep (54.6%, N= 187) while serval cat exclusively predates on poultry (22.26% n = 134) (Table 3).

Table 3. Livestock predation prevalence between September, 2019 and August, 2022 in GMCCA.

Livestock	Season		Total loss	Loss per household	African wolf	Spotted Hyena	Leopard	Serval cat
	Wet	Dry						
Sheep	1103	403	1506	5.25	1328	76	102	0
Goat	72	13	85	0.3	0	0	85	0
Horse	101		101	0.35	0	101	0	0
Mule	5	0	5	0.01	0	5	0	0
Donkey	5	0	5	0.01	0	5	0	0
Poultry	465	137	602	2.1	468	0	0	134
Dog	68		68	0.24	0	68	0	0
Total	1819	553	2372	8.26	1796	255	187	134

Time-based variations in livestock depredation

The time of the day for attacking on livestock varied among predators. Spotted hyenas were reported to attack livestock at the enclosures during the night time more often than when grazing (χ^2 = 164.80, df = 1, $p < 0.001$) which showed that there is a significant difference in time of predation. In contrast serval cat

predate more on poultry (N= 118) in the day time than the night which is significantly different at (χ^2 = 77.64, df = 1, p < 0.001). The attacks by African wolf (N = 1796) and leopard (N = 187) were reported to occur during the day in the grazing areas. Most of the incidents (89.63%, N=2126), of domestic animal depredation occurred during the day time while few (10.37%, N=246) occurred at night time (χ^2 = 1490.05, df = 1, P < 0.001) (Figure 2).

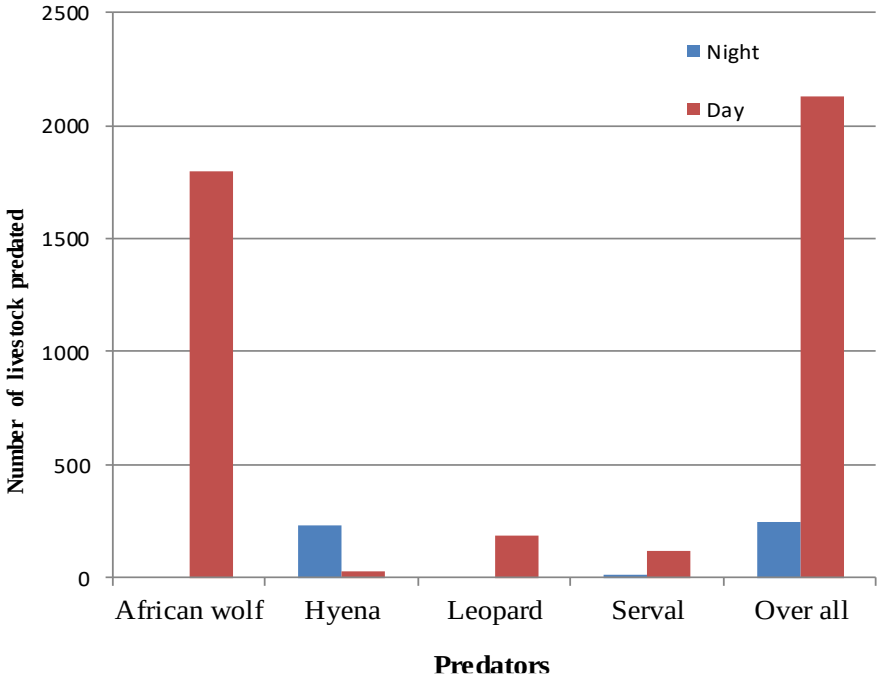

Figure 2. Number of livestock predation by different carnivore predation during the time of day and night in GMCCA.

Spatial patterns of livestock depredation

During the study period, the highest depredation levels were reported in Tirb Godin (418) and Amba Wonz (325) villages while slightly lower number of livestock loss were reported in Mesobo (35) and Adara (27) villages (Figure 3). The mean annual livestock loss as reported for all predators was three heads of stock per household per year. A leopard was reported to be the only predator of goats in Kefoye, Gundan Afaf, Ambagr and Yetenfo villages causing loss of 85 goats. The losses differed significantly with in villages (χ^2 = 16.51, df = 3, p = 0.001).

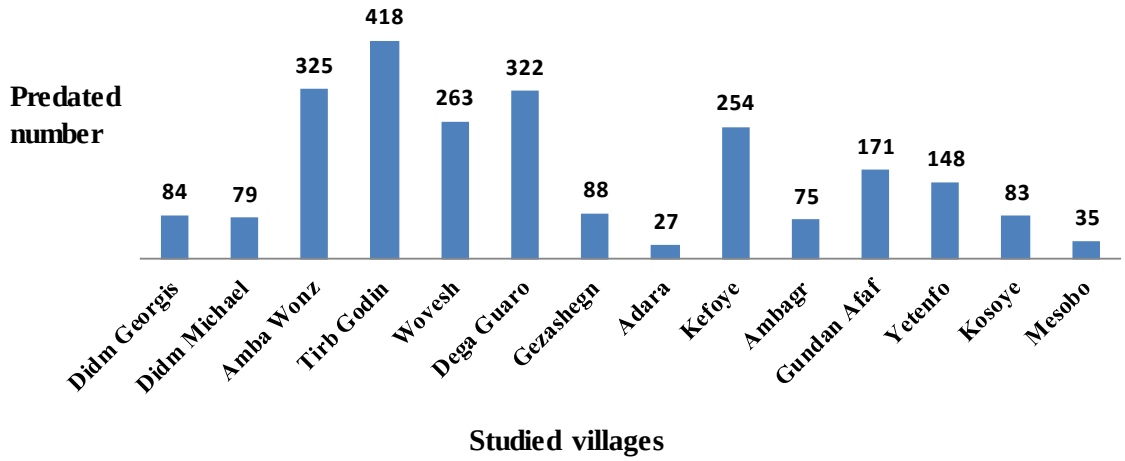

Figure 3. Total number of livestock predated in different villages around GMCCA.

Livestock predation intensity increased around the protected area relative to the distance. Distance to the protected area and the frequency of domestic animal loss by predators were negatively correlated (rho = -0.625, $p < 0.001$).

Seasonal patterns of livestock depredation

More than three quarters (76.69% N=1819) of reported attacks by all carnivore species occurred during the rainy season, while (23.3% N=553) were reported to have occurred in the dry season. It was significantly different at ($\chi^2 = 675.7$, df = 1, $P < 0.01$). African wolf, Hyena, Leopard and Serval were reported to attack livestock significantly more often in the rainy season than the dry season (African wolf $\chi^2 = 349.26$, df = 1, $p < 0.001$; Hyena: $\chi^2 = 251.02$, df = 1, $p < 0.001$; Serval: $\chi^2 = 25.1$, df = 1, $p < 0.001$; leopards: $\chi^2 = 138$, df = 1, $p < 0.001$ (Figure 4).

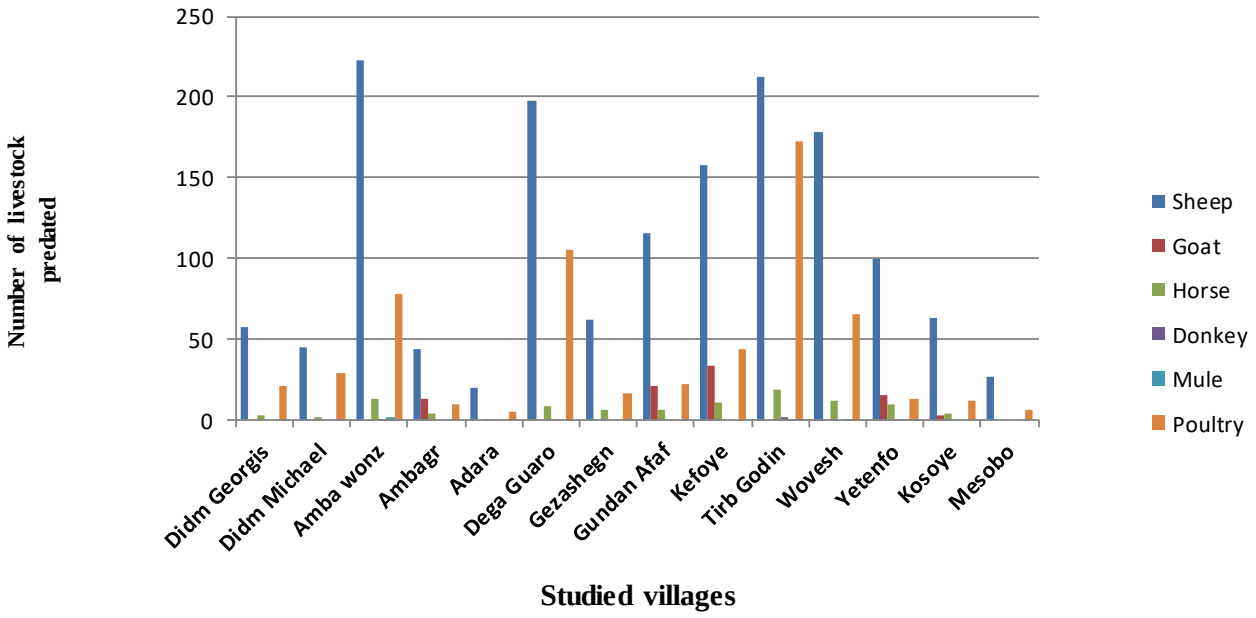

Figure 4. Number of livestock predated in different villages around GMCCA for the last three years

About 84.7% of the death of goats occurred during the rainy season and when the animals were herded in the field, while 15.3% of goat death occurred in the dry season. Similar trend was observed for sheep where about 73.24% of death of sheep occurred during the rainy season, while 26.76% occurred in dry season. Most losses (77.24%) of poultry occurred during rainy season, while 22.76% of it occurred in the dry season. Horses, donkeys and mules were attacked in the rainy season and no attack incidences were reported in the dry season.

Economic value of livestock loss

The economic revenue lost due to livestock predation in GMCCA over the three years was about $136 per household per year. Hyena was the cause for relatively small proportion of the kills (10.75%, N= 2372), however the economic loss was higher because it kills large and more expensive livestock species including horses, donkey and mule. The greatest proportion of livestock and financial losses were reported on sheep in proportion to their relative abundance ($90,557, N = 1506) (Table 4). There was a significant difference

in terms of financial valuation of livestock losses (χ^2 = 316,804.12 df = 5, p < 0.001, N= 2372) and in terms of financial impact among the predators (χ^2 = 136, 430.16, df = 3, p < 0.001).

Table 4. Potential revenue lost as a result of livestock predation around GMCCA.

Carnivore	Total		Sheep		Goat		Horse		Mule		Donkey		poultry	
	N	USD	N	USD	N	USD	N	USD	N	USD	N	USD	N	USD
African Wolf	1796	82,867	1328	79870									468	2997
Leopard	187	12,458	102	6135	85	6323								
Serval cat	134	858											134	858
Hyena	187	20,803	76	4570			101	13993	5	1795	5	445		
Total	2304	116986	1506	90575	85	6323	101	13993	5	1795	5	445	134	3855

Methods of livestock protection

Farmers used various methods to keep safe their domestic animals against predators during the night and the day time. These include using enclosures, guarding with dogs at night and guarding with herdsmen around the grazing field in the day time.

During night time, about 89.2% (N= 256) of the respondents kept all their livestock in underground shelter made up of stone and wood that cannot be easily penetrated by hyenas and leopards, while 2.4% of them kept their livestock in a grass hut. However, 8.4% (N=24) of them which kept their livestock in enclosures with thin walls. In addition, all of the respondents used dogs to guard the livestock during the night time. Underground shelter was reported to be the best preventive method of livestock predation by carnivores (Figure 5). There is a significant difference (χ^2 = 27.33 df = 1, p < 0.001) among the protection methods used (enclosure with thin walls, grass hut and underground shelter)

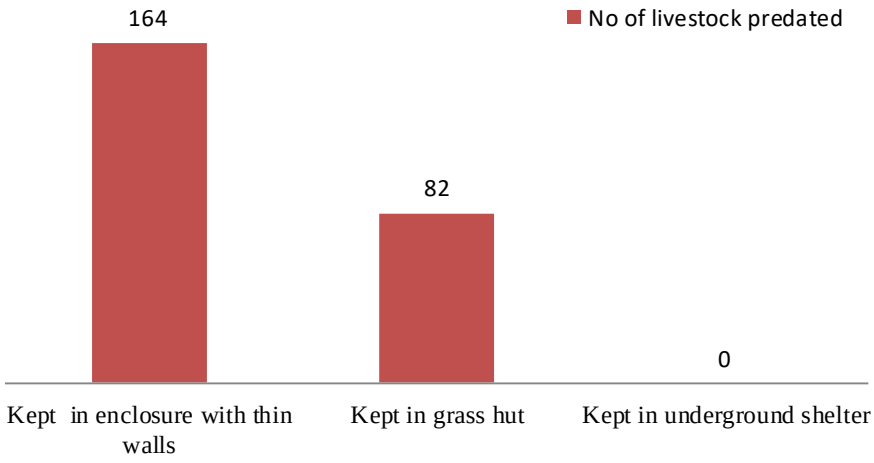

Figure 5. Number of predated livestock in the three preventive methods during the night time around GMCCA.

DISCUSSION

The community at GMCCA suffered from livestock predation as many of the Ethiopian highlands. Livestock loss per household per year was 2.8 in which sheep contributed the largest share (1.75 per household /per year). Similar findings were also reported in Guassa mountains of Ethiopia, where out of 0.66 livestock predated per household per year sheep contributed the largest proportion, 0.6 per household per year (Atickem et al., 2017). Also, in Bale mountain national park, 0.65 livestock were predated per household per year (Atickem et al., 2010).

The economic loss caused by livestock predation in GMCCA is $136 per household per year. Due to a very high inflation in Ethiopia, the price of livestock changed a lot during the last decade, and direct comparison of the loss across the Ethiopian highland studied at different periods is difficult. Earlier studies on other highlands reported $12 per household per year in Bale Mountain National Park (Atickem et al., 2010) and $33.6 per household per year Guassa Community Conservation Area (Atickem et al., 2017).

In some African countries, the loss by livestock predation is by far larger than the loss in Ethiopia. Muriuki (2013) in the Amboseli ecosystem in Kenya and Mkonyi et al., (2017) in the Tarangire ecosystem, Tanzania

reported that each household lost $1628.7 and $633 annually, respectively. A study conducted by Narisha, (2015) in Laisamis district, Kenya, reported that four animals killed from each household resulting in loss of $207 per household per year.

In the GMCCA, the most serious predator was African wolf causing two livestock loss per household per year ($96.24 loss per household per year). African wolf was also reported to be the most important predator in the other northern Ethiopian highlands, Guassa community conservation area where it was responsible for 74.6% livestock loss (492 total kills) contributing $19.8 per household per year (Atickem et al, 2017). Similarly, African wolf is the primary predator of sheep in Simien Mountain National Park causing the loss of 1.14 livestock per household per year (Mesele et al., 2009) and in Choke Mountain, central Ethiopian highlands, it resulted in loss of two livestock per household (Bezihalem et al., 2017).

The most predated livestock in GMCCA is sheep contributing 63.5 % of the total killed livestock. This is likely to be due to the high number of sheep in the study area and leaving sheep for grazing without any herder. The attacks mainly occur during the day in the grazing areas. Similar results were reported by earlier studies (Koirala et al., 2012, Khan et al., 2018). Also, in Marsabit District, Kenya, 90% of livestock predation occurred on grazing herds from 130 total livestock kills (Kruuk, 1981).

African wolf also feed on poultry in the GMCCA while this is not reported in other Ethiopian highlands (Atickem et al., 2010 and 2017; Mesele et al., 2009), but it was reported to kill poultry in Sodo Community Managed Conservation Forest (Yigrem et al., 2016).

Hyenas were reported to be responsible for all types of domestic animal depredation in GMCCA. While hyena kills lower number of livestock, it kills large and high value livestock such as horse, mule and donkey. Hyena is an important livestock killer Ethiopia and many other African countries. In the Web Valley area of Bale Mountains (Ethiopia) and Lake Nakuru National Park and Soysambu Conservancy (Kenya), hyena was identified as the most important predator resulting loss of $10 and $197.7 per household per year respectively (Atickem et al., 2010; Koskey, 2021). In Zimbabwe, hyenas were responsible for < 2%

domestic animal predation in the Kogwe communal area (Butler, 2000) whilst in Builimamangwe Communal Area; hyenas were reported to be the most prevalent livestock predator (Hawkes, 1991). Similarly, in Kenya, hyenas were reported to be responsible for <10% of the livestock depredation adjacent to Tsavo National Park and causing loss of $339 per year (Patterson et al., 2004), whereas they were reported to be responsible for 53% (74) of the predated livestock adjacent to the Maasai Mara National Reserve (Kolowski and Holekamp, 2006).

The third most important livestock predator in GMCCA is Leopards which depredated 85 goats and 102 sheep during the sty period. Most of the kills were in five villages close to church where leopard uses as a refuge. Other researches also reported goat as most vulnerable and frequently depredated livestock in Maasai steppe in Northern Tanzania by leopard (Kissu, 2008). In Bale Mountain national park leopards depredated 105 goats and 17 sheep in a three years period of time (Atickem et al., 2017).

The fourth predators in GMCCA is Serval cat which predated on poultry and causing relatively lower economic cost to the households due to the low price of poultry compared to other predated livestock. A study conducted by Yigrem et al. (2016) also identified serval cat as a predator that predated poultry in Sodo Community Managed Conservation Forest, Ethiopia.

Most incidents of livestock and poultry predation (89.63%) occurred during the day time in GMCCA. The attacks by African wolf were reported to occur during the day in the grazing areas while hyenas attack livestock during the night time. Similar findings were reported from areas where African wolf and hyena were identified as main predators (Kruuk, 1981; Atickem et al., 2010, 2017; Fulla, 2015; Narisha, 2015) Mkonyi et al., 2017). A different finding was reported from a study in Mandi district, India, where the highest number of killing (74.5%) occurred at night time (Sethi et al., 2011). This difference might be due to the differences in methods of herding, climatic condition, enclosure type and the type of predator involved.

The present study suggested that the distance of the villages from the protected area is an important factor in determining the extent of domestic animal depredation by wild animals. The results showed that the closest villages to the protected area experienced the highest frequencies of livestock depredation by the predators. This is because higher populations of carnivore species are found in the villages located close to the protected area (Holmern et al., 2007). As reported in many other studies (Kolowski and Holekamp, 2006; Sillero-Zubiri and Laurenson, 2001).

There are different livestock protection methods from predation in the studied villages. Most of the reported attack during the day time was associated with methods of herding system in villages surrounding GMCCA. Similar results were reported by, Alemayehu and Mathewos (2015), Atickem et al. (2010), Gidey and Bauer (2010). Thus, increasing the number of herders and adult people during main season of conflict is the most effective method (Ogada et al., 2003).

The study also showed that in the night time lower numbers of domestic animals were depredated. This is due to construction of underground shelter made up of stone and wood which reduced losses to carnivores. Similar result was reported in Menz Guassa Community Conservation Area, Ethiopia (Atickem et al., 2017). Therefore, constructing of underground shelter is very important to protect the predation of livestock at night time and will be valuable to reduce conflict (Butler, 2000). In addition, using a well-trained domestic dog is a good method to reduce depredation which alerts herders during the approach of carnivores (Dickman, 2009; Atickem et al., 2010).

CONCLUSION AND RECOMMENDATION

This study concluded that livestock predation by spotted hyena**,** African wolf and leopard causes more financial losses to the people living in and around GMCCA. African wolf killed livestock during the day time while sheep are at grazing fields, hence the critical measure in reducing the loss should focus on livestock management during grazing. The predation is in particular high in the rainy season and hence a better livestock management is required during this season. Livestock predation increased with deceasing

distance from the GMCCA which is expected as the area inhabits the larger proportion of the African wolf. Additionally, doing a buffer zone of the GMCCA may significantly reduce the loss due to livestock predation. Livestock predation by hyena is relatively low likely due to strong shelter built in the area which could be an important example to implement in other Ethiopian highlands where hyena predation is high. The livestock predation causes a substantial loss for the community of the GMCCA who have low income. Thus, identifying the fundamental drivers of the conflict and raising awareness on how to mitigate the problems could help in minimizing the losses caused by predators.

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THE ROLE OF REPRODUCTIVE TECHNOLOGIES AND CRYOPRESERVATION OF GENETIC MATERIALS IN THE CONSERVATION OF ANIMAL GENETIC RESOURCES

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ABSTRACT: The conservation of animal genetic resources guarantees the continual existence of diversified nature and thereby ensures the achievement of valuable economic, ecological, social, and cultural demands. However, animal genetic resources are currently facing several threats, such as climate change, habitat loss, pollution, invasive species, and infectious diseases. Animals can be conserved in situ in their natural habitat, ex-situ in zoos and farms, and in vitro in gene banks. Thus, the main objective of this review is to provide a comprehensive overview of the role of reproductive technologies and cryopreservation of genetic materials in the conservation of animal genetic resources. The cryopreservation of genetic materials is capable of generating new offspring and has critical importance in the conservation of threatened animal species. Advanced reproductive technologies, including artificial insemination, in-vitro fertilization, embryo transfer, and nuclear transfer, greatly promoted efficiencies in animal production and conservation. Cryopreservation of genetic materials, including semen, oocytes, embryos, and somatic cells, and assisted reproductive technologies are advantageous in the conservation of genetic resources. Reproductive technologies have been successful in reconstituting animal populations and recovering endangered and extinct animals from cryopreserved genetic materials across the world. In Ethiopia, the application of reproductive and cryopreservation technologies is mainly restricted to livestock genetic improvement. Semen collection and preservation have started for the conservation of threatened cattle breeds and the endangered Ethiopian wolf. Therefore, reproductive and cryopreservation technologies should be extensively applied for sustainable animal conservation. Special emphasis should be placed on the development and application of cryopreservation and reproductive technologies.

Keywords: Animal genetic resource, Conservation, Cryopreservation, Reproductive technologies, Threatened

INTRODUCTION

Animal genetic resources refer to the diverse species, breeds, and strains of animals that serve important purposes for humans and their environment, including economic, ecological, scientific, and cultural roles (EBI, 2016; FAO, 2023). Animal biodiversity has multilateral contributions, and the demand for animal

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genetic resources is definitely certain for human-contented livelihoods as they provide a variety of animal products and services (Pilling et al., 2020). Animals develop survival and adaptation traits for their ecology and production systems. However, the loss of animal genetic resources is currently a global concern. They are facing multiple threats that endanger their survival which include changes in land use, exploitation, climate change, pollution, invasive species, inbreeding, and infectious diseases (Givens, 2010; Engdawork, 2019). Therefore, the conservation of animals is crucial to ensure the sustainability and diversity of animal genetic resources. Conserving animal genetic resources involves maintaining genetic diversity to conserve, restore, and improve animal breeds and species (Mmassy, 2011).

The various approaches for the conservation of animal genetic resources, include in-situ conservation on farms, ex-situ in-vivo conservation in farms or zoos, and ex-situ in-vitro conservation in gene banks (Andrabi and Mawxell, 2007). Assisted reproductive technologies (ARTs) and cryopreservation of genetic materials play significant roles in the conservation of animal genetic resources. The collection and preservation of genetic materials, such as embryos, semen, oocytes, somatic cells, and tissues, have the potential to reconstitute live animals (Mazur et al., 2007). Ex-situ conservation of genetic materials enables effective protection of genetic resources, along with in-situ conservation of animals (Hiemstra et al., 2011). Advanced reproductive technologies, such as germplasm collection and cryopreservation, multiple ovulation and embryo transfer, sperm and embryo sexing, in-vitro fertilization, nuclear transplantation, and cloning, are great support for animal conservation efforts (Herrick, 2019).

Assisted reproductive technologies (ARTs) can be successfully used for the conservation and restoration of species and breeds in danger of extinction (Paiva et al., 2016). The preservation of biomaterials, such as semen, oocytes, embryos, tissues, or DNA in animal gene banks (AnGB), is essential to the conservation of animal genetic resources (Andrabi and Mawxell, 2007). Animal gene banks allow the collection and storage of genetic material for many years without deterioration through cryopreservation and create wide opportunities for the restoration of a particular animal population after disasters or epidemic events

(Comizzoli et al., 2000). Reproductive technologies encourage the utilization of frozen germplasm stored for extended periods of time, thereby maintaining the genetic diversity of a species or breed (Pukazhenthi and Wildt, 2004; Bolton et al., 2022).

Assisted reproductive technologies consist of various techniques, such as cryopreservation of gametes and embryos, artificial insemination (AI), in-vitro fertilization (IVF), and embryo transfer (ET). ARTs greatly promote efficiencies in animal reproduction and serve as a significant tool for conserving domestic and wildlife populations that are threatened with extinction (Swanson, 2006; Bolton et al., 2022). In Ethiopia, the use of reproductive technologies is primarily focused on improving cattle productivity through genetic improvements. Semen collection and artificial insemination are the most widely used reproductive technologies (Azage et al., 2016). However, advanced reproductive and cryopreservation technologies have not been well implemented in the conservation of endangered and threatened animal species and breeds. As such, animal conservation strategies need to adopt advancements in cryopreservation and reproductive technologies. Therefore, the main objective of this review is to provide a comprehensive overview of the cryopreservation of animal genetic materials and the role of reproductive technologies in the conservation of animal genetic resources.

CRYOPRESERVATION OF ANIMAL GENETIC RESOURCES

Cryopreservation is an advanced biotechnology that allows germplasm to be stored for long periods of time in small, confined areas. It is a procedure where gametes, somatic cells, and tissues are gradually frozen using liquid nitrogen to achieve extremely low temperatures (Weathers and Prien, 2014). The most commonly preserved samples include semen, embryos, oocytes, somatic cells, nuclear DNA, and other types of biomaterials such as blood and serum (Mazur et al., 2007). This process enables the preservation of the genetic material of both maternal and paternal cells for use in assisted reproductive technologies and maintains viability over extended periods. Therefore, it can be applied as a contingency plan when a

particular animal species or breed needs to be restored when it has become extinct or for breed improvement purposes (Mendelsohn, 2003; Jinadu et al., 2020).

Cryopreservation of animal genetic resources is necessary for the utilization of genetically merited animal breeds for desired traits, the preservation of genetically and phenotypically diverse populations, and the conservation of animal breeds and species threatened with extinction (Danchin-Burge et al., 2011). The diversity of livestock and wildlife has huge contributions to sustainable agricultural development, food security, and ecological balance, as they are adapted to variable environmental conditions and diseases (Herrick, 2019). Cryogenically preserved genetic materials are used for the conservation and rehabilitation of threatened breeds with low populations, reviving animal species or breeds that are endangered or extinct, and genetic improvements (McEvoy et al., 2000; Larsen, 2021).

Semen collection and cryopreservation

Semen is collected from animals for different purposes, including assessing reproductive performance, artificial insemination, and conservation of animal breeds and species (Coloma et al., 2010). Semen collection and preservation is the most commonly used biotechnique for germplasm preservation and conservation of threatened animal species due to its ease of application. Semen can be collected from animals using artificial vaginas, electro-ejaculation, and digital or manual massage (Thongphakdee et al., 2022). Semen is most commonly collected using artificial vaginas, particularly in domestic animals, and this method is relatively the best method for bringing good-quality semen (Wulster-Radcliffe et al., 2001). Electro-ejaculation is used in animals that cannot mount or are fractious for management, such as wild animals (Palmer et al., 2005). Semen collection by rectal massage of the seminal vesicles and ampulla is possible whenever both of the above procedures are not suitable to apply (Thongphakdee et al., 2022). The suitability of a particular method depends on the type and condition of the animal.

The cryopreservation of semen involves semen collection from the donor animal, evaluation, extension, and gradually freezing in liquid nitrogen for long-term storage (Vongpralub et al., 2015). Semen collection and

preservation is a necessary prerequisite to the development of assisted reproductive technologies such as artificial insemination, in-vitro fertilization, and embryo transfer and can be applied to several animal species (Rodriguez-Martinez and Vega, 2013). Semen collection is practiced throughout the world for genetic improvement through cross-breeding, conservation of threatened animals, and restoration of endangered or extinct animal species and breeds. Accordingly, global trends indicate that semen can be collected from most domestic and wild animal species.

Cryopreservation of embryos

The collection and cryopreservation of embryos is a potential biotechnological development for the purpose of protecting population integrity and conserving endangered animal species. Even if it is a complex and expensive procedure, the embryo conserves the full genetic complement of both dam and sire and maintains heterozygosity (Pukazhenthi and Wildt, 2004). Embryos develop through various morphological stages following fertilization. During embryonic development, the number of blastomeres increases as they migrate through the female reproductive tract. Thereby, the embryos can be collected from donor females by flushing the reproductive tract using a physiological flushing medium. The superovulation technique using follicle-stimulating hormone is usually performed in order to have a female release more oocytes than usual (Pomar et al., 2005).

The cryopreservation of embryos requires the necessary freezing processes and techniques. Vitrification is the preferred technique of the embryo freezing protocol, as it produces good and viable embryos (Rezazadeh et al., 2009). It is the practice of freezing embryos, which is achieved with an extreme increase in cryoprotectant thickness and ultra-rapid cooling to solidify the cell into a glass-like state without intracellular or extracellular ice crystal formation. Applying a higher concentration of the medium during vitrification enables the germplasm to be frozen more rapidly than with slow freezing (Vajta, 2000; Loutradi et al., 2008). As embryos contain the full genetic make-up of animals, cryopreservation of embryos is

technically a more reliable method for the restoration of extinct animals and the conservation of threatened animal species.

Collection and cryopreservation of Oocytes

Oocytes are another type of germplasm that can be cryopreserved for the conservation of animal genetic resources. In contrast to semen and embryos, oocytes are extremely sensitive to chilling due to the fact that they typically have a low permeability to cryoprotectants (Woods et al., 2004). Several progresses have been made towards the successful collection and cryopreservation of oocytes from different animal species (Andrabi and Maxwell, 2007). Cryoprotective solutions achieve cellular dehydration by avoiding intracellular ice crystal formation during freezing. Vitrification is considered the best-suited freezing technique for the preservation of oocytes (Huijsmans et al., 2023). Oocytes can be collected by harvesting ova from ovaries in dead animals and by ova pick-up in live animals using the transvaginal ultrasound-guided oocyte collection method (Carter et al., 2002; Farsi et al., 2016). The cooling of ovaries during harvesting dramatically reduces the success rate of embryo production.

In a conventional way, oocytes are often harvested from slaughterhouse ovaries immediately after slaughter and can be an option for cryopreservation. The conventional procedure of oocyte collection has a significant advantage for preserving the genetic resources of females that unexpectedly die or are incapable of being bred (Farsi et al., 2016). The cryopreservation of oocytes provides higher possibilities for the collection and storage of oocytes from dead animals and is one of the best ways to preserve female genetic material postmortem. Moreover, technically, oocytes can be collected and preserved for most mammalian species.

Cryopreservation of somatic cells

Cryopreservation of somatic cells is an alternative means of conserving genetic resources, particularly in situations where semen and oocytes cannot be collected and preserved. The collection and preservation of tissues, DNA, blood, and other biomaterials enable the storage and usage of genetic resources (Di Lecce et al., 2022). The conservation of somatic cells is related to somatic cell nuclear transfer (SCNT), which

enables the restoration of threatened or extinct animal species. The collection of tissues other than gametes and embryos can also be used for applied and developmental research to get genetic and health-associated information (Li et al., 2009). Cryopreserved cells and tissues can be stored for long periods of time without deterioration and provide opportunities for the conservation of animal genetic resources.

Somatic cells for somatic cell nuclear transfer and DNA study can be collected and cryopreserved from the tissues of live and dead animals within a short period of time. Live animal tissue can be taken from the ear or other peripheral tissues, while tissue can also be easily obtained from dead animals immediately after death (Araujo et al., 2006). The collected tissue samples are preserved through different cryopreservation techniques, including slow freezing and vitrification. Slow freezing of cells or tissues allows the specimens to be frozen below the melting point with liquid nitrogen in a medium. The vitrification technique is achieved by applying a higher concentration of solute so that the water leaves the cells through osmosis (Loutradi et al., 2008).

The role of reproductive technologies in animal conservation

The development and application of ARTs to enhance reproductive performance have valuable importance in ensuring the sustainable conservation of animal genetic resources (Herrick, 2019). Nowadays, many vertebrate species face variable threats and extinctions. The major significance of reproductive technologies is that they ex-situ resuscitate threatened and endangered animals, thereby conserving valuable and rare alleles (Mastromonaco and Songsasen, 2020). Assisted reproductive techniques help to recover small, endangered, and fragmented populations of wild animal species or domestic breeds (Figure 1). ARTs create an important opportunity for producing many offspring from a desired genitor in the way they minimize inbreeding problems (Comizzolia et al., 2000; Bolton et al., 2022).

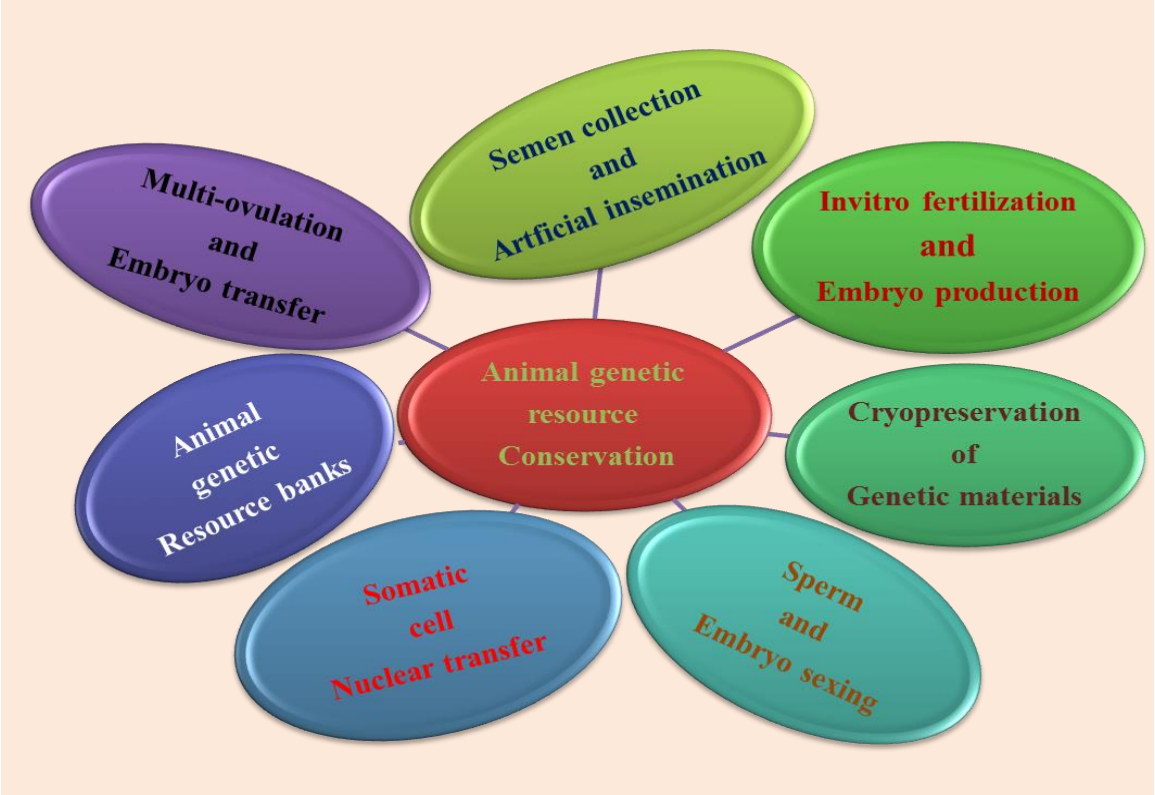

Figure 1. The role of reproductive technologies and cryopreservation of genetic materials in the conservation of animal genetic resources.

Artificial Insemination (AI)

Artificial insemination (AI) is the physical placement of semen into the female reproductive tract by a method other than natural mating. AI is the most commonly used reproductive technology, which is less complex and expensive, and consequently the main choice in the conservation and breeding programs for threatened wild and domesticated animal species and breeds (Durrant, 2009). The conservation of animal populations located in fragmented sites can be enhanced through the application of AI, thereby avoiding genetic depression (Pukazhenthi and Wildt, 2004). A female animal from a small population can be inseminated with semen from a male animal of the species from another site and sent back to their habitat. Male animals can also be easily captured from their freely living environment and semen collected for insemination of females held in captivity (Bolton et al., 2022).

Artificial insemination techniques can be applied to most mammalian species, playing a considerable role in the conservation of variable domestic and wild animal species. The availability of infrastructure and simple techniques for semen collection, evaluation, and preservation attracts the use of frozen and extended semen in animal conservation and breeding, and AI has become a widely applied reproductive technology (Zuidema et al., 2021). There are differences among species in insemination techniques and the success rate of pregnancy with the use of frozen semen and AI (Vazquez et al., 2005). The ease of the technique and its applicability make AI a very suitable reproductive technology for animal breeding and conservation. AI is practiced for most mammalian species, birds, and reptiles.

Multiple Ovulation and Embryo Transfer (MOET)

Multiple ovulation and embryo transfer are very important reproductive technologies that can significantly support efforts in animal production and conservation. MOET is a procedure in which fertilized eggs are removed from a female donor and transferred to multiple female receivers that are genetically unrelated (Hasler, 2004). Even if it is an advanced assisted reproductive technology, the application of the MOET technique is not widespread in most animal populations. However, MOET is a key biotechnology in conservation strategies in which multiple eggs are released from a single dam and embryos are transferred from endangered species to non-threatened recipients (Jainudeen et al., 2000). Synchronization and super-ovulatory protocols are commonly applied to multiple ovulations and embryo transfer techniques. Superovulation and embryo transfer programs have become successful in conserving and restoring several endangered animal species, such as baboons, wild sheep, eland antelope, Grant's zebra, and Przewalski’s horse (Bettencourt et al., 2008).

The stimulation of ovarian follicle growth by induction of follicular stimulating hormones, the initiation of estrus through luteolytic treatment, the preparation of insemination, and the collection of embryos are the basic procedures during the application of the MOET technique in animal production and conservation (Mikkola and Taponen, 2017). The MOET technique can also be applied for the treatment of infertile

females due to disease, injury, or aging. The other importance of this technology is to decrease disease transmission risk across species and geographically (Shenk et al., 2006). Collecting and transferring embryos is a relatively challenging and complex procedure, and careful techniques should be utilized to successfully collect and transfer embryos (D'Angelo et al., 2022). In principle, the surgical technique of embryo transfer is almost possible in all mammalian animal species. However, the non-surgical embryo transfer technique is possible in some animal species, like cattle, horses, and pigs, while it may be ineffective or impossible in other species (Robertson, 2014).

In-vitro Fertilization and Embryo Production (IVP)

In-vitro embryo production (IVP) is the collection, fertilization, and maturation of oocytes in an artificial environment (outside the female reproductive tracts). In-vitro fertilization (IVF) of mature oocytes and culturing of embryos is performed at the level at which the embryo's developmental stage is suitable for the embryo transfer to the recipient female (Freitas and Melo, 2010). IVF and embryo production are usually accompanied by multi-ovulation, oocyte collection, and the use of fresh or frozen extended semen, which makes it a valuable way of conserving threatened or endangered animal species. The application of this technique in the conservation strategy is basically based on knowledge of the reproductive physiology of the animal species (Herrick, 2019).

In-vitro fertilization and embryo production constitute sequential steps, including oocyte recovery and their in-vitro maturation (IVM), in-vitro capacitation of sperm, in-vitro fertilization, and the growth of the embryos until they are ready for embryo transfer (Comizzoli et al., 2000). Utilization of in-vitro fertilization and IVP techniques for conservation of threatened species has been performed in Armenian red sheep, Sika deer, and European mouflon (Comizzoli et al., 2001; Ptak et al., 2002), African elephant (Loxodonta africana), mink whale (Meintjes et al., 1997), gorilla (Gorilla gorilla), and zebra (Tetsuka et al., 2004). The success and viability are confirmed by the gestations and births of normal offspring after transfer to recipient animals (Locatelli et al., 2006).

Somatic Cell Nuclear Transfer (SCNT)

Somatic Cell Nuclear Transfer (SCNT), also called cloning, is the technique where the DNA (nucleus) is extracted from a donor cell and transferred to an enucleated recipient cell, thereby creating a strictly similar genetic makeup of the donor cell (Andrabi and Maxwell, 2007). SCNT technology has been considered in the conservation and population increment of threatened breed populations since the first success in the cloning of mammals (Wilmut et al., 1997). There are trends in the restoration of extinct animal species, such that the extinct bucardo (*Capra pyrenaica pyrenaica*) has become a good exemplary animal species born with success by nuclear transfer of somatic cells (Table 1). Nowadays, the application of SCNT for the re-establishment of threatened animal species occurs mainly through interspecies nuclear transfer (Folch et al., 2009).

Reproductive cloning is applicable in several species, but irrespective of the animal species, there are three basic procedures to apply: enucleation, injection or fusion, and activation. SCNT involves the collection, culturing, and in-vitro development of the ovum, removing the nucleus from the ovum, and inserting somatic cell nuclei into the enucleating ovum. Thereby, an embryo is cultured and finally transferred to the recipient female of the same or highly related species (Matoba and Zhang, 2018). Successful offspring have been achieved through somatic cell nuclear transfer in a number of mammalian species, including sheep, cattle, mice, pigs, goats, horses, rabbits, and cats (Table 1).

Table 1. Application of somatic cell nuclear transfer (SCNT) and the successful production of new offspring in mammalian species.

Types of cloning	Donor species	Donor cell type	Recipient oocyte species	References
Intraspecies	Pig	Fetal fibroblasts	Pig	(Onishi et al., 2000)
Interspecies	Gaur (*Bos gaur*)	Preserved adult skin cells	Cow (*Bos taurus*)	(Lanza et al., 2000)
Intraspecies	Pig	Cultured adult granulosa cells	Pig	(Polejaeva et al., 2000)
Interspecies	Mouflon (*Ovis orientalis musimon*)	Adult granulosa cells	Sheep (*Ovis aries*)	(Loi et al., 2001)
Interspecies	Zebu (*Bos indicus*)	Morula stage blastomere	Cow (*Bos taurus*)	(Meirelles et al., 2001)
Intraspecies	Rabbit	Adult transgenic cumulus cell	Rabbit	(Chesne et al., 2002)
Intraspecies	Cat	Adult cumulus cells	Cat	(Shin et al., 2002)
Intraspecies	Mule	Fetal fibroblasts	Horse	(Woods et al., 2003)
Intraspecies	Horse	Adult skin fibroblasts	Horse	(Galli et al., 2003)
Intraspecies	Rat	Fetal fibroblasts	Rat	(Zhou et al., 2003)
Interspecies	African Wildcat (*Felis lybica*)	Adult skin fibroblasts	Cat (*Felis catus*)	(Gomez et al., 2004)
Interspecies	Banteng (*Bos javanicus*)	Cryopreserved adult fibroblasts	Cow (*Bos taurus*)	(Janssen et al., 2004)
Intraspecies	Dog (*Afghan hound*)	Adult skin fibroblasts	Dog (golden retriever)	(Lee et al., 2005)
Intraspecies	Ferret	Adult cumulus cells	Ferret	(Li et al., 2006)
Interspecies	Gray wolf (*C. lupus*)	Adult ear fibroblasts	Dog (*C. familiaris*)	(Kim et al., 2007)
Intraspecies	Red deer	Adult antlerogenic cells	Deer	(Berg et al., 2007)
Intraspecies	Buffalo	Fetal fibroblasts and adult granulosa cells	Buffalo	(Shi et al., 2007)
Interspecies	Pyrenean ibex (*Capra pyrenaica*)	Cryopreserved skin fibroblasts	Goat (*Capra aegagrus hircus*)	(Folch et al., 2009)
Intraspecies	Camel	Adult cumulus cells	Camel	(Wani et al., 2010)
Interspecies	Coyote (*C. latrans*)	Neonatal/adult fibroblasts	Dog (*C. familiaris*)	(Hwang et al., 2013)
Interspecies	Bactrian camel (*Camelus bactrianus*)	Adult skin fibroblasts	Dromedary camel (*C. dromedaries*)	(Wani et al., 2017)
Intraspecies	Cynomolgus monkey	Fetal fibroblast	Cynomolgus monkey	(Liu et al., 2018)

Sperm and Embryo Sexing

Sperm and embryo sexing is an advanced development for effectively managing the sex of offspring in multi-ovulation and embryo transfer technology. Embryo sexing is a useful technique as a conservation tool for managing the sex ratio in endangered animal species. Population analysis should be thoroughly conducted before embryo sexing to ensure a balanced sex ratio in at-risk groups. Sex prediction was 100% achieved in 58 bovine embryos when the blastomeres dissociated from a morula exceeds three (Zoheir and Allam, 2010). Similar achievements have been recorded in the sex determinations of 43 goat embryos of single blastomere at the blastula stage. This technique can be effectively applied to the sex determination of bovine and ovine embryos (Tsai et al., 2011).

There are two different approaches to the sexing of embryos, which are categorized as non-invasive and invasive methods depending on the requirement for a biopsy of embryonic tissue. Invasive methods, such as karyotyping and identification of sex chromatin, do not maintain embryonic integrity, while non-invasive methods (detection of X-linked enzymes and H-Y antigen) maintain integrity and cause less damage to the embryo (Wakchaure et al., 2015). Each of the methods has its own advantages and disadvantages in the sexing procedures. During the selection of embryo sexing techniques, the percentage accuracy and viability of the embryo produced must be taken into consideration. Among the available methods, polymerase chain reaction is taken to be a simple, effective, extremely reliable, and precise procedure for sexing embryos (Lakshmy et al., 2018).

Application of reproductive technologies for animal conservation in Ethiopia

Reproductive technologies in animal conservation

The application of reproductive technologies in Ethiopia is mainly restricted to the genetic improvement of livestock production. Semen collection and artificial insemination are the first and most commonly applied reproductive technologies in the livestock industry (Figure 2). AI is widely practiced throughout the country by agricultural offices, dairy industries, and institutions (Chencha and Kefyalew, 2012). Reproductive

technologies such as oestrous synchronization, multi-ovulation, mass artificial insemination, and embryo transfer have been practiced in livestock to a limited extent by agricultural and research institutions in the country (Azage et al., 2016). Artificial insemination has been practiced in cattle, sheep, and goats for crossbreeding, mostly on commercial dairy farms.

Figure 2. Mass oestrous synchronization and artificial insemination in cattle in Ethiopia (Ndambi et al., 2017)

There are few practices in the application of reproductive technologies for the conservation of animal genetic resources in the country. Semen is collected and cryopreserved from some indigenous cattle breeds, such as Sheko, Begait, Fogera, Irob, and Borana, at the initiation of the Ethiopian Biodiversity Institute (EBI, 2016). Interestingly, semen collection trials were conducted for the endangered Ethiopian wolf. However, it was a big challenge to obtain good-quality semen as Ethiopian wolves have a restricted and narrow window of breeding time within the year. The presence of a strict hierarchy for mating affects the production of viable sperm good enough for storage with adequate fertility in adult males other than the alpha male (Farstad, 2017).

Opportunities for application of reproductive

The collection and preservation of genetic resources and the application of assisted reproductive technologies significantly improve the conservation of endangered animals, along with in-situ conservation efforts. The availability of threatened and highly endangered species of animals in the Ethiopia presents

good opportunities for the application and expansion of reproductive technologies. The extensive use of AI and current developments in practicing other reproductive technologies (multi-ovulation, in-vitro fertilization, and embryo transfer) by research institutions can be a huge support for conservation and farm animal improvement (Desalegn et al., 2009). Different stakeholders, including non-governmental organizations, are likely interested in taking part in the development and use of reproductive technologies in the conservation of threatened animal species (EBI, 2016).

The presence of several threats, such as global climate change and recurrent drought in pastoral and agropastoral areas of Ethiopia, inbreeding's in endangered domestic and wild animals, crossbreeding and breed dilution in the central highlands, and habitat loss, bring huge opportunities for the application of reproductive and cryopreservation technologies. Herewith, the current infrastructural development and capacity of experts allow the application of assisted reproductive technologies in the conservation of animal genetic resources. Semen can be collected from almost all farm animals and endangered wild animals for use in AI and embryo transfer. Female gametes and embryos can also be collected, preserved, and transferred, particularly in highly endangered mammalian species.

Constraints in the application of reproductive technologies for animal conservation

The major constraints to the development and utilization of reproductive technologies in Ethiopia are related to the lack of good infrastructural and financial support. The lack of skilled manpower and technicians is one of the main challenges. There are also difficulties related to access, affordability, and community awareness of the extensive application of reproductive technologies. Moreover, the complexity and cost-demanding nature of advanced technologies like in-vitro production and embryo transfer impose greater constraints. Thus, there is low efficiency in the application of reproductive technologies (Adane, 2009). The limitations in our understanding of the reproductive physiology of threatened animal species reduce the success rate of reproductive technologies. Effective application of ARTs requires adequate knowledge of the reproductive status, seasonality, and behaviors of the particular species (Wildt and Wemmer, 1999).

Technical advances in reproductive science allow the development and effective application of ARTs in the conservation of threatened animal species (Le Gac et al., 2021).

CONCLUSION AND RECOMMENDATIONS

The development and application of reproductive technologies and cryopreservation of genetic materials play significant roles in realizing the sustainability and conservation of animal genetic resources. The most commonly cryopreserved genetic materials include semen, oocytes, embryos, and somatic cells. Reproductive technologies have made significant achievements in strengthening in-situ conservation programs, establishing threatened animal populations, and rehabilitating extinct animal species. Artificial insemination, multi-ovulation and embryo transfer, in-vitro fertilization and embryo production, somatic cell nuclear transfer, and embryo sexing are the most important reproductive technologies for animal conservation. In Ethiopia, many animal species and breeds are threatened due to climate change, recurrent drought, inbreeding, crossbreeding, and habitat loss. However, the application of reproductive technologies is limited to the genetic improvement of livestock and the conservation of a few threatened cattle breeds. Therefore, cryopreservation of genetic materials and assisted reproductive technologies should be extensively applied to the sustainable conservation of animal genetic resources. Special emphasis should be given to facilitate the global transfer of knowledge and resources in the development and application of cryopreservation and reproductive technologies.

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Ethiopian Journal of Biodiversity

Guideline for contributors

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- **Research papers -** Research papers should not exceed 8000 words in length, including Figures, Tables and References. Moreover, they should not contain more than 10 Figures and/or Tables
- **Review papers -** Critical and comprehensive reviews that provide new insights into or interpretations of the subject through a thorough and systematic evaluation of available evidence that should not exceed 10,000 words including Figures, Tables and References
- **Short communications -** Short communications such as opinions and commentaries should not exceed 1500 words and they must be brief definitive reports which need not be divided into Materials and Methods, Results and Discussions
- **Book Reviews -** Book review which is a critical evaluation of published books in any discipline of biological sciences/biodiversity will be published under this column

2. Manuscript preparation

2.1 Article style and structure

Manuscripts should be written in American English, typed double-spaced, on A4 size, with margins of 1.5 cm on top and bottom sides of the paper, 2 cm on left and 1.5 cm on the right. A font size of 12 points (Times New Roman) should be used throughout the manuscript. The major sections of the manuscript include title, abstract, keywords, introduction, materials and methods, results, discussion, conclusion and recommendation, acknowledgements and references. Those sections having headings and sub-headings should not have more than three levels. All pages and lines should be numbered with the title page being page1

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Desikan, S. and Ramesh, G. 2006. Software testing. Bangalore, India: Dorling Kindersley.

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Harlan, J. R. 1971. On the origin of barley: a second look. In: R. A. Nilan, ed., Barley Genetics vol. II Proc. 2nd Barley Genetics Symposium. Washington State Univ. Press, Pullman, pp. 45 - 50.

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Engels, J. M. J. 1994. Genetic diversity in Ethiopia in relation to altitude. *Genetic Resources and Crop Evolution*, **41: 61-73**.

Lemessa, D., Hylander, K. and Hambäck, P. 2013. Composition of crops and land use types in relation to crop raiding pattern at different distances from forests. *Agriculture Ecosystems and Environment*, **167:71-78**.

Mewded, B., Negash, M. and Awas, T. 2020. Woody species composition, structure and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia. *Journal of Forestry Research*, **31(4): 1173-1186**.

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Raina, S. 2015. Establishing Correlation Between Genetics and Nonresponse. *Journal of Postgraduate Medicine*, [online] **61(2):148**. Available at: http://www.proquest.com/products-services/ProQuest-Research-Library.html [Accessed 8 Apr. 2015].

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Avogel.com, 2015. *A. Vogel plant encyclopaedia.* [online] Available at: https://www.avogel.com/plant-encyclopaedia/ [Accessed 20 Apr. 2015].

6.2.6 Citation in text

One author: The last name of the author followed by year of publication will be cited in the text.

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- Referee suggestions and their contact details (optional)

8. Proofreading

PDF proofs are to be sent by email to the corresponding author for correction. Authors are responsible for the final proofreading of their manuscripts and no corrections are accepted after re-submission. The corrected version should be returned to the editor-in-chief/associate editor within a week.

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