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Modeling habitat quality for rangeland ecosystem restoration in the Alledeghi Wildlife reserve, Ethiopia

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Assessment of habitat quality is important for the planning and management of conservation measures at a landscape level. The Alledeghi Wildlife Reserve (AWR) is an iconic wildlife conservation area because it not only contains charismatic wildlife species but also serves as a reliable livestock rangeland. The study aimed to assess habitat quality based on landscape-specific habitat threat information in the AWR using InVEST software. it is the first attempt to model the habitat quality of the landscape using expert-driven information. Six important threats were considered, namely, invasive species, bush encroachment, livestock incursion, fire, habitat destruction, and distance to roads. The quantified habitat quality was classified into low, moderate, and high. The results revealed that the quality of the habitat declined in the study area between 1998 and 2016. The high-quality habitat had a larger extent covering about 837 km^2 (57.4%) in 1998 but it was reduced by 128 km^2 (64%) during the study period. Conversely, moderate quality and low-quality habitats have increased from 78 km^2 (5.35%) in 1998 to 206 km^2 (14.12%) in 2016; and from 544 km^2 (37.3%) in 1998 to 619 km^2 (42.13%) in 2016 respectively. The decline in habitat quality was mainly associated with increased livestock incursion and expansion of invasive species which resulted in rapid land use changes. Thus, it is critical to undertake serious conservation measures to enhance biodiversity and ecosystem services in the AWR and to substantively contribute to the improved livelihood of the pastoral community.

KEYWORDS

AWR, biodiversity, ecosystem quality, InVEST, rangeland

1 Introduction

Biodiversity enhances ecosystem functionality which leads to improved ecosystem services through balancing and stabilizing ecological communities across scales (Cardinale et al., 2012; Oliver et al., 2015). The biodiversity of an area can be determined through habitat conditions whereas the importance of habitat depends on its quality (Basane and James, 2016). A particular habitat with special ecological importance is essential to the functioning of the wider ecosystem processes; such areas require extraordinary protection to safeguard the special value and vital ecosystem processes. Biological resources and the levels of biological reproduction and organism persistence have a greater effect on the ability of an ecosystem to provide living conditions for individual organisms and populations (Caro et al., 2020).

High-quality habitat is assumed as an indication of rich biodiversity (Norliyana and Mamat, 2020) and delivery of a suite of ecosystem services (Johnson, 2007; Stolton et al., 2010; Thomas et al., 2021). The state of biodiversity can be used as a basis proxy tool to measure the quality of a given habitat (Havlicek and Mitchell, 2014). Therefore, as a proxy for the condition of the state of biodiversity, quality habitat can indicate the capability of a given ecosystem to provide essential ecosystem services (Polasky et al., 2011) and as a determinant for measuring ecosystem health (Villamagna et al., 2013). The occurrence of diverse wildlife species is highly associated with the quality of habitat (Edmonds et al., 2021).

Habitat quality is an important indicator of regional ecological security (Zhu et al., 2015; Chen et al., 2016), which can reflect the level of regional biodiversity and ecosystem services (Tang et al., 2020; Zhu et al., 2020). Rigorous information on habitat quality is invaluable to making informed decisions on conservation planning and prioritization of conservation intervention strategies (Rouget et al., 2003; Baral et al., 2014; Simeneh et al., 2023) including expansion of important biodiversity areas, introduction and removal of species, and identification of principal habitat components (Basane and James, 2016) and determining of the key ecological attributes.

The landscape changes lead to corresponding modifications in the composition of the ecosystem and biodiversity (Liu et al., 2022). Further habitat quality changes affect the biodiversity and landscape pattern (Chu et al., 2018). Therefore, the occurrence of severe and complex ecological problems at landscape and species levels have a direct influence on the landscape pattern and habitat quality. Understanding the association between conservation challenges caused by land use change could provide a solution to ecological problems (Bai et al., 2019). Habitat loss consistently negatively affects species richness and population abundance (Laurance et al., 2002); and genetic diversity (Aguilar et al., 2008). The loss of critical habitats affects not only biodiversity but also directly impacts humans by decreasing the production of ecosystem services such as pollination (Potts et al., 2010), soil productivity and water provision (Bruijnzeel, 2004), and carbon storage and sequestration (Fargione et al., 2008).

The state of biodiversity, the range of habitats, and vegetation types across landscapes can be determined using the InVEST habitat quality and rarity models (Sharp et al., 2020; Liu et al., 2022). Thus, the changes in habitat quality are critical to the changes in ecosystem processes (Choudhary et al., 2021; Yang, 2021). Habitat quality monitoring provides robust information on ecological conditions and can be utilized as a basis for making habitat conservation interventions (Lin et al., 2016). Changes in habitat quality have tremendous implications for the conservation of wildlife species in savannah ecosystems (Kija et al., 2020) where the ecosystems are the principal habitats for diverse charismatic wildlife species and home to many iconic protected landscapes (Sinclair et al., 2007; Bohm and Hofer, 2018).

The Alledeghi Wildlife Reserve (AWR) is among the highly valued protected landscapes in Ethiopia which are highly pronounced with the assemblage of large mammals, but it is under severe conservation challenges, and the biodiversity endowment of the area particularly large mammals alarmingly declining (Fanuel, 2013; Simeneh et al., 2016). The important threats to biodiversity are steadily increasing such as the fast spread of invasive species, overgrazing, and bush encroachment (Almaz, 2009; Selamnesh, 2015) because of rapid Land Use Land Cover (LU/LC) changes, the ecosystem services values of the area have greatly declined (Simeneh, 2023). Moreover, urban development along the road is becoming an emerging conservation threat that will constrain the sustainability of the ecosystem (Almaz, 2009; Fanuel, 2013). Further, intensive charcoal production is well-pronounced in the entire area. Thus, this results in massive habitat destruction in the adjacent protected areas including the Awash National Park. Roadkill incidence has repeatedly occurred while wild animals are crossing the asphalted road in search of water (Simeneh et al., 2016). Fire incidence mainly in the highland forest is becoming a very common challenge for protected area management as local charcoal makers deliberately set fire to produce more charcoal.

The study hypothesizes that habitat quality declined over time in response to threat factors occurring in the study area. There is a lack of empirical studies conducted in the study area that assessed the status of the habitats to protect the values that the protected area possessed. Therefore, the novelty of this study is that it is the first attempt to model the quality of habitats of the protected landscape using expert-driven landscape threat information and analysis to indicate the state of the protected areas towards meeting its conservation goal. Therefore, this study aimed to assess the spatiotemporal changes in the quality of the habitat in the terrestrial ecosystems of AWR using InVEST software to provide a scientific basis for ecosystem planning interventions and prioritization of conservation management undertakings.

2 Methods and materials

2.1 Description of the study area

The AWR was established in the 1960 s (Hilliman, 1993). It is located in the Great Rift Valley in the northeastern region of the country between longitude 39°30′to 40°30′E and latitude 8°30′to 9°30′N, at 280 km east of Addis Ababa (Figure 1). The altitude ranges between 776 m and 2,445 m above sea level. The area is characterized by a semi-arid ecosystem with annual rainfall ranging between 400 and 700 mm. About 268 plant species and two types of ecosystems Dry evergreen montane forest and Acacia comiphora ecosystems (Addisu et al., 2017), 31 species of mammals, and over 140 avian species have been recorded (Hilliman, 1993; Fanuel, 2013) in the AWR. The most common wild animals inhabiting the reserve include the Grevy zebra (Equus grevyi), Beisa oryx (Oryx beisa beisa), Soemmering's gazelle (Gazella soemmering), Gerenuk (*Litocranius walleri*) and lesser kudu (Tragelaphus imberbis) (Hilliman, 1993).

The major vegetation types in and around the reserve include grasslands, bushland, woodland, riverine forests, and highland forests (Almaz, 2009). The grassland plain stretching from the center of the reserve to the northwest was mainly occupied by grasses and occasionally with other herbs; the dominant species include Durfu (Chrysopogon plumulosus), Isisu (Chrysopogon schoenan) and Malif (Andropogon canaliculatus) (Almaz, 2009; Selamnesh, 2015). However, the rapid encroachment of shrub species and the rapid spread of invasive Prosopis juliflora and shrubs such as Combretum aculatum, Merua oblongflora, and Terminalia species have affected the grass species and the extent

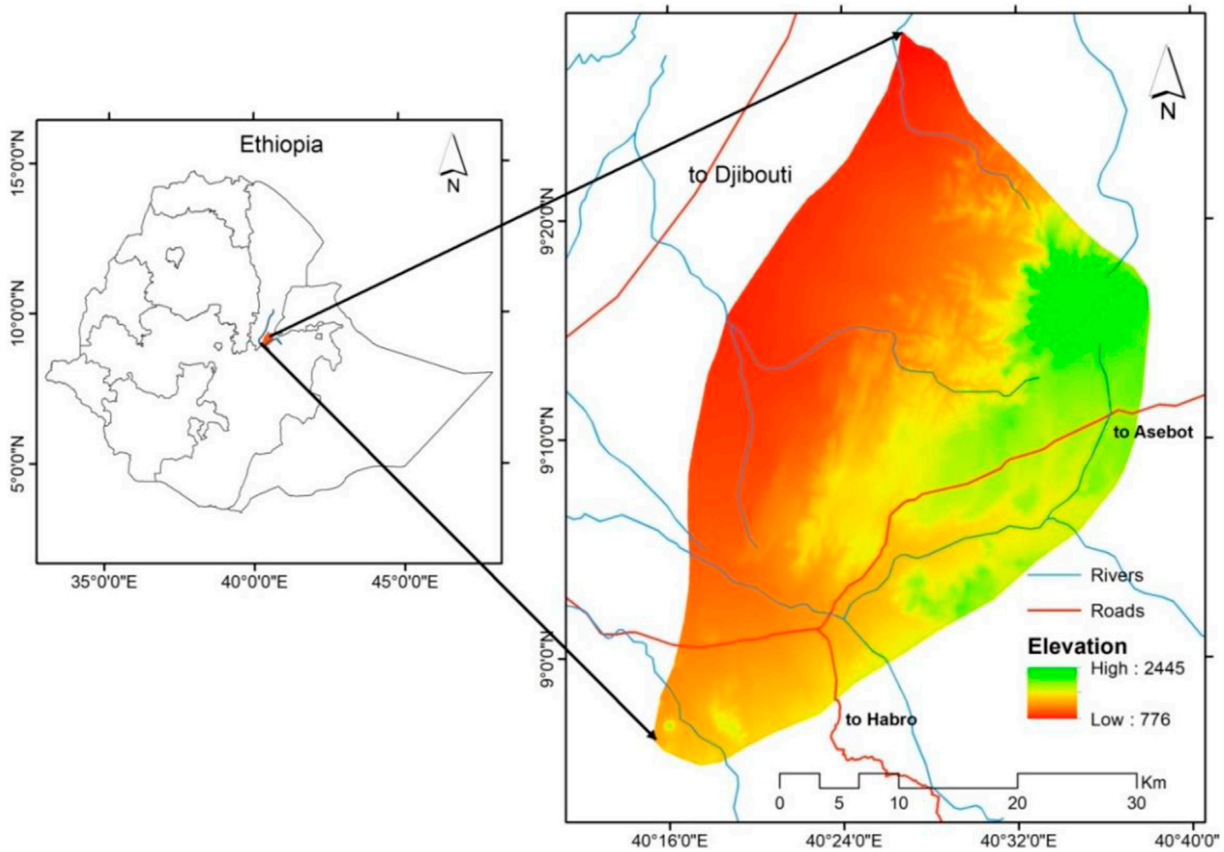

FIGURE 1
Map of the Alledighe landscape.

of the grassland habitat (Selamnesh, 2015; Simeneh, 2023). The bushland is an extensively increasing habitat type that possesses an assemblage of trees and shrubs (Simeneh, 2023). The habitat is mainly occurring in the southern, eastern, and northern edges of the landscape dominated by Acacia senegal (Almaz, 2010; Selamnesh, 2015). The common woody plant species in the AWR include Acacia tortilis, Acacia mellifera, Balanitis aegyptiaca, Cadaba, and Grewia species. The eastern mountainous section of the landscape is characterized by dense highland forest, common plant species include Cordia africana, Croton macrostachyus, Erythrina abyssinica, Juniperus procera, Olea europaea, Podocarpus falcatus, Pouteria altissima and Rhus vulgaris (Almaz, 2010). The riverine forests are a unique ecosystem and are important for the wild animals of the landscape. It is limited to seasonal streams and river courses where the water table is high.

2.2 Materials

2.2.1 Application of tools to assess habitat quality

Habitat quality can be assessed based on measured species diversity or through the analysis of the evolution of the habitat by parameter substitution (Andrus et al., 2021). In general, comparing observations to a standardized list of criteria can be used to assess the quality of a given habitat (Machado, 2004), and more recently the standardized modeling tool, particularly the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) has been largely applied to measure the quality of habitat at various scales (Sharp et al., 2020). In this study, we assessed the state of habitats using InVEST software 3.11 version. The quantified habitat quality was classified by natural breaks into three classes (low, moderate, and high) (Kija et al., 2020).

2.2.2 The InVEST habitat quality model

The InVEST model provides good research methods and perspectives (Romero-Calcerrada and Luque, 2006; Terrado et al., 2016; Abreham et al., 2020). The model incorporates land use and biodiversity threats information to produce habitat quality maps. It uses the spatial extent of habitat quality as a proxy of biodiversity within the landscape, based on the proximity of the habitat to human-dominated land use and the intensity of disturbance caused by the land use (Sharp et al., 2020). The model considers that LU/LC with higher habitat quality is relatively intact and capable of supporting increased biodiversity and a lower habitat quality score indicates reduced biodiversity support and denotes a degraded landscape (Baral et al., 2014). The model is dependent on the relative impact of threats to the habitat, the distance between the threat sources and the habitat, and the sensitivities of the specific habitats to any possible threats, leading to habitat degradation (Sharp et al., 2020) (Table 1).

TABLE 1 Description of data input for the habitat quality model in InVEST.

Input	Description
Land use land cover	GIS raster dataset, with a numeric LULC code for each cell. The LULC raster obtained from Simeneh (2022) in the area of interest was used. The LULC codes must match the codes for the sensitivity of land cover types to each threat
Threat data	A CSV table of all threats needed to be considered in the model. The table contains information on each threat's relative importance or weight and its impact across space. Each row is a degradation source. Each column contains a different attribute of each degradation source and must be named as THREAT, MAX-DIST, WEIGHT, and DECAY.
Threat raster	GIS raster files with the distribution and intensity of each threat showing each of them affecting the habitat. However, the techniques applied for each threat raster can vary according to the data types. The threat maps should cover the area of interest and buffer the width of the greatest maximum threat distance. Each cell in the raster contains a value that indicates the density or presence of a threat within it. All threats should be measured on the same scale and units
Habitat types and sensitivity of each habitat to threats	A CSV table of LULC types contains information on whether a habitat is identified (absence/presence of habitat) or not and their specific sensitivity to each threat. Sensitivity values range from 0 to 1, where 0 represents no sensitivity to a threat and 1 represents the greatest sensitivity (Polasky et al., 2011). Sensitivity scores can be determined using expert knowledge and the AHP method (Hamere et al., 2021)
Half saturation constant (k)	The scaling parameter (or constant) of 0.5 is the default for the InVEST model. The InVEST model uses a half-saturation curve to convert habitat degradation scores to habitat quality scores (Sharp et al., 2020). It is determined as an inverse relationship between the degradation and habitat quality scores. It helps with the visual representation of heterogeneity in quality across the landscape

TABLE 2 Ecological habitat quality input data used for InVEST habitat quality model in the AWR (1998, 2016).

Threats	Maximum distance (km)	Weight	Decay	LULC types				
				BL	HF	GL	RF	WL
				Habitat suitability score				
				1	1	1	1	1
				Habitat sensitivity to threats				
Invasive species	1	0.25	Exponential	1	0.1	1	1	1
Habitat destruction	2	0.25	Exponential	0.75	0.75	0.5	0.5	0.75
Livestock incursion	2	0.15	Exponential	1	0.5	1	1	1
Bush encroachment	3	0.05	Exponential	1	0.5	1	0.75	0.75
Fire	1	0.05	Linear	0.2	0.5	0.2	0.2	0.2
Distance to road	1	0.1	Linear	0.5	0.75	1	0.5	0.2

There are three key inputs to be considered for habitat quality mapping in InVEST model. First, the suitability of each LU/LC type (H_j) for providing habitat for biodiversity; second, anthropogenic threats that originate at pixel x (r_x) affecting habitat quality; and third, the sensitivity of each LU/LC type to each threat (Table 1). For this study, six biodiversity threats were identified in the study area by following the approach of Terrado et al. (2016) and Wu et al. (2014). These were invasive species, bush encroachments, livestock incursion, fire, habitat destruction, and distance to roads (Table 2). The significance (weight) of each threat was prioritized based on the ecological and threat monitoring activities with two senior ecologists and five park rangers of the AWR between 3rd—4th December 2021 and the AHP method was applied to prioritize conservation threats following the approach by Terrado et al. (2016) and Wu et al. (2014) (Table 2; Figure 2).

The total threat level in a grid cell x with LU/LCj is calculated as the relative habitat suitability score (H_j), from 0 to 1, where 1 indicates the highest suitability to species has been assigned to LU/LC types (Sharp et al., 2020). The last input of the model is the sensitivity of habitat type to different threats; helps to account for the differentiated impacts of threats to different habitats. The impacts of the threats on the habitat are determined by 1) the effect of the threat over space (i_{rxy}); 2) the relative weight of each threat's importance compared to the others (w_r), and 3) the relative sensitivity of each habitat to each threat (S_{jr}). The stress level D_{xj} of grid x with land-use type j is calculated as follows (Sharp et al., 2020).

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{rmax}}\right) \text{ . . . . if linear . . . . } (1)$$

$$i_{rxy} = \exp\left(-\left(\frac{2.99}{d_{rmx}}\right)d_{xy}\right) \text{ . . . . if exponential . . . . . . } (2)$$

Where, d_{xy} is the linear distance between grid cells *x* and *y*, and d_{rmax} is the maximum effective distance of threats r's across space.

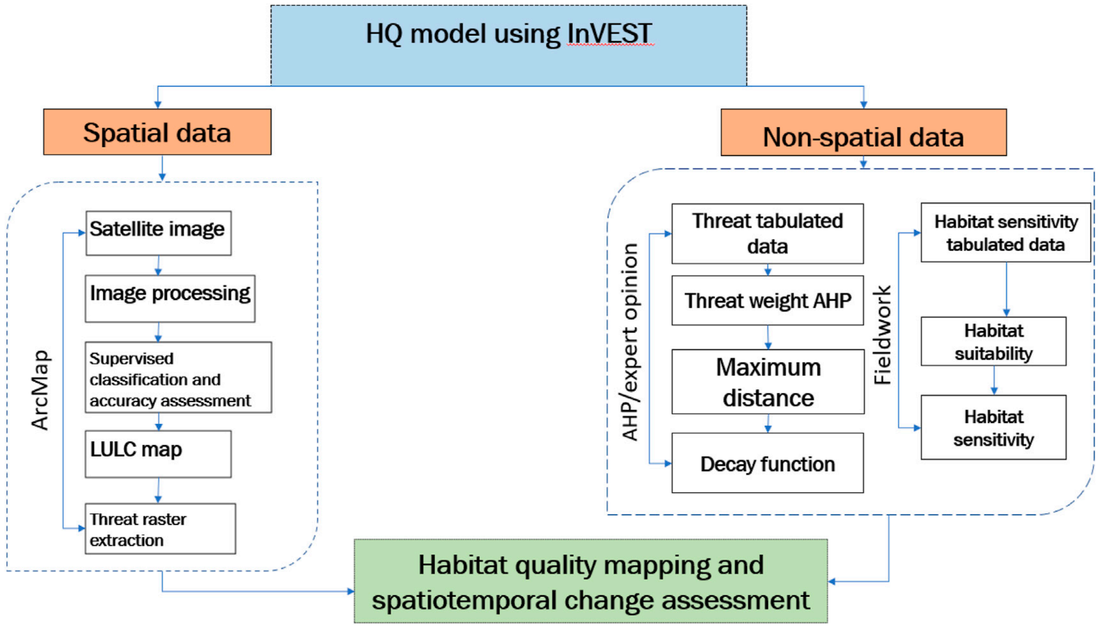

FIGURE 2
Flowchart showing methodological steps followed in the study.

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Yr}\left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_x i_{rxy} \theta_x S_{jr} \ldots\ldots\ldots\ldots \quad (3)$$

where R is the number of threat factors, y_r is the set of grid cells on r's map, w_r is the relative effect of each threat, θ_x is the level of accessibility to a grid cell x, and S_{jr} is the relative sensitivity of each habitat type to each threat.

The results of the model range from 0 to 1, with 1 representing the highest level of habitat quality (Sharp et al., 2020). The impacts of the threat on habitat decrease as the distance from the degradation sources increases, threats with higher destructive values (on the scale of 0-1) have higher impacts and the more sensitive a habitat type is to a threat (higher S_{jr}), the more degraded the habitat type could be by the threat.

Habitat quality is the environmental level that the ecological environment provides for the survival of individual organisms and populations. It is a continuous variable with a numerical range from low to high. The higher the quality of the habitat, the more stable the ecological structure and function of the patch. The way and intensity of human land use determines the quality of the habitat, and the more intense the land use, the more pronounced the decline in habitat quality (Almpanidou et al., 2014). Habitat quality was calculated based on the degree of habitat degradation, and the habitat quality score decreased with increasing habitat degradation score. The calculation formula for habitat quality is as follows:

$$Q_{xj} = H_j\left[1 - \left(\frac{D_{xj}^2}{D_{xj}^2 + k^z}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where, Qxj is the habitat quality of grid cell x in land cover type j; Hj is the habitat suitability of land cover type j; D^2 xj is the level of habitat threat for grid cell x in land cover type j; k is the half-saturation factor, which is generally taken as half of the maximum value of D^2 xj; and x is a constant.

The information obtained from expert judgment and AHP was verified by undertaking field assessments.

2.3 Data preparation and input for the InVEST habitat quality model

The data inputs (spatial and non-spatial) are required to run the InVEST habitat quality model (Figure 2). Thus, LU/LC maps, threat sources, and impacts, habitat types, habitat sensitivity to each threat, and half-saturation constant were the required inputs (Sharp et al., 2020). The information on LU/LC was obtained from the previous study made by Simeneh (2023) in the study area. All the required inputs such as LU/LC maps of the respective years (1998–2016), threat sources and impacts, habitat types, and habitat sensitivity to each threat were loaded to run the habitat quality model. Finally, habitat quality maps for each respective year were produced; the final habitat quality maps were classified into three classes (low, moderate, and high).

3 Results and discussions

The result revealed an overall habitat quality reduction during the study period (Table 3; Figure 3). The model showed that the ecosystem was dominated by a high-quality habitat of 837 km^2 (57.4%) followed by a moderate-quality habitat of 544 km^2 (37.3%), and a low-quality habitat of 78 km^2 (5.35%) in 1998. In the subsequent 18 years (1998–2016), the low-quality and moderate-quality habitats increased by 128 km^2 (62%), and 75 km^2 (12%) respectively, while the high-quality habitats decreased by 203 km^2

TABLE 3 Habitat quality changes in the AWR using the InVEST habitat quality model (1998, 2016).

Habitat quality	Study period				Change (km²)	% change	Trend
	1998		2016				
	Area (km²)	%	Area (km²)	%			
Low	78	5.35	206.00	14.12	128.00	62.14	Increasing
Moderate	544	37.29	619.00	42.43	75.00	12.12	Increasing
High	837	57.37	634.00	43.45	−203.00	−32.02	Decreasing
Total	1,459	100.00	1,459.00	100.00			

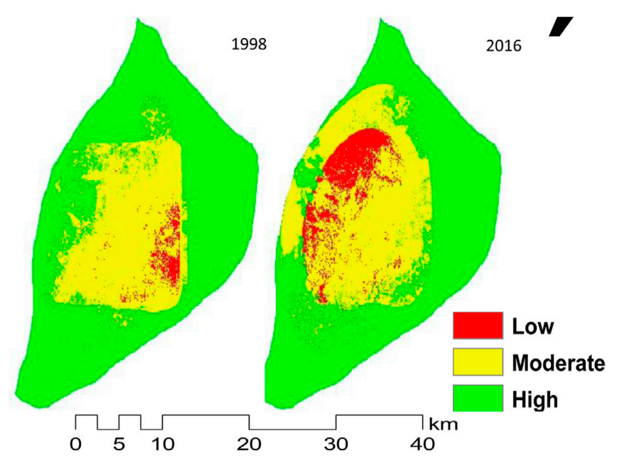

FIGURE 3
Spatial distribution of habitat quality in the AWR (1998, 2016).

(32%). The extent of high-quality habitat largely declined during the study period from 837 km² (57.4%) to 534 km² (43.45%). Conversely, moderate-quality, and low-quality habitats have increased from 78 km² (5.35%) in 1998 to 206 km² (14.12%) in 2016; and from 544 km² (37.3%) in 1998 to 619 km² (42.13%) in 2016 respectively.

This study was the first to assess habitat quality using InVEST model and expert-driven approach in Ethiopia's highly valued protected landscape. Thus, the study provides robust information that can be used for threat reduction planning and management intention in the study landscape. The habitat quality changes in the study area were highly associated with increased livestock incursion and expansion of invasive species resulting in severe changes in the healthy functioning of the ecosystems. The quality of habitat influences wildlife species diversity, density, distribution, and movement patterns in landscapes (Zhang et al., 2019; Dai et al., 2018). The decline in habitat quality is mainly attributed to increased conservation threats including the incursion of livestock and human interactions into wildlife habitats (Carter et al., 2014). Free grazing activities have an adverse negative impact on habitat quality (Su et al., 2020). Likewise, the quality of the habitat has been significantly declining particularly the grassland habitat was deteriorated by massive livestock incursion in the study landscape, which is a common prolonged problem in protected areas of Ethiopia (Mekbeb et al., 2022). Similar results were reported by Kija et al. (2020) that habitat quality has largely deteriorated by anthropogenic activities and land use policy changes in the Greater Serengeti Ecosystem of Tanzania.

Overall, high–quality 1998 became a moderate-quality and low-quality habitat during 1998–2016. The loss of habitat quality is well pronounced in the grassland habitat of the protected area which is the preferred feeding and breeding habitat for charismatic ungulate species and other wild animals of the AWR. The swift spread of invasive species coupled with livestock grazing and habitat destruction significantly affects the grassland habitat of the protected area. The savannah grassland habitat is the most preferred and suitable habitat for the charismatic plain animal of the reserve but under severe pressure, particularly invasive *Prosophis juliflora* in the grassland habitat is the principal conservation challenge for the protected area management. The communities are reliant upon livestock rearing and natural resources due to a lack of alternatives leading to overgrazing; unmanaged grazing practices are resulting in significant degradation of principal ecological habitats such as the grassland habitat in many protected area systems in Ethiopia. Due to the high livestock density in the area, the grassland habitat of the landscape has encountered severe grazing practices year after year. This has led to the deterioration of grassland habitat quality and a reduction in the capacity to provide forage for grassland-reliant wild animal species.

Land use and land cover changes can be taken as the prime factors for changes in habitat quality in the study area during the study period. The low-quality habitat has slightly shifted from the center of the highland forest to the center of the landscape which is occupied by the grassland habitat of the AWR (Figure 3); this is mainly due to the spread of invasive species, livestock incursion, and the closeness to the tarmac road. The highland forest has been unwisely utilized for various purposes mainly for charcoal production, however, improved management intervention in the highland forest contributed to the management of illegal activities thus the habitat has rapidly been restored (Simeneh, 2023). Conversely, the grassland habitat was largely converted into low habitat quality as unrestricted grazing led to reducing the quality of grassland habitat. The woodland, riverine forest, and partially bushland habitats have been unchanged in terms of quality and maintained high habitat quality during the study period. According to Fanuel (2013), the study landscape has lost about 52% of its quality to conserve the larger charismatic herbivores of the landscape. Similarly, this finding showed that only 634 km²

(43.45%) of the landscape sustains its high quality to possess charismatic species of the landscape. This indicates that the protected landscape is losing its quality habitats to possess the endangered iconic species. Maintaining high-quality habitats could enhance the stability of ecosystem structure and function and the quick recovery potential of habitats after disturbance (Schwarz et al., 2017; Wu et al., 2017).

Unlike most areas of Ethiopia in which invasive species were spread due to the road access; in the Afar area, where the landscape is located; Prosopis juliflora was introduced mainly for water and soil conservation and to support livestock forage in the dry season in the late 1970 s and early 1980 s (Ayanu et al., 2014; Kebede and Coppock, 2015; Hailu et al., 2019). Further, additional plantations were made between the 1980 s and 1990 s as shade and wind protection trees in villages, and the raw material was used for firewood fencing, and building materials (Ayanu et al., 2014). Livestock has been identified as the principal vector for the rapid spread of invasive species and the invasion become a serious problem that started rapidly invading the rangeland (Hailu et al., 2019). The invasion could significantly affect the ecosystem services and livelihood of pastoralist communities by reducing biodiversity, grazing land, and water supply (Shackleton et al., 2014).

4 Limitations of the study

The assessment of habitat quality using the InVEST model has been successfully employed for the maintenance of biodiversity and is invaluable for the management of the landscape and land-use planning (Sharp et al., 2020) but inadequate information about the spatial and temporal distribution of species across the protected landscape (Stephen et al., 2011) is the major limitations of the InVEST habitat quality model. It is, therefore, important to conduct a field-based habitat suitability assessment to obtain ecologically valid and robust information on the distribution of quality habitat and species abundance across the landscape (Nagendra et al., 2013).

5 Conclusion

This study has assessed the quality of habitat using expert-driven landscape habitat threat information in InVEST software in the most iconic but greatly threatened protected landscape of the AWR in Ethiopia. Assessing a landscape's habitat quality has greater implications for the larger rangeland ecosystem management since it directly impacts landscape structure and spatial pattern. The most important factors for the decline of habitat quality include livestock incursion and the expansion of invasive species. Therefore, it can be concluded that the continued fast spread of invasive species and bush encroachment in the critical feeding and breeding habitat can largely influence the biodiversity and ecosystem services of AWR. Thus, it is critical to undertake serious conservation measures to maintain the ecosystem's integrity and halt biodiversity loss. Further, the boundary of the AWR has not been clearly defined and has not been legally gazetted yet. Therefore, the findings of this study can be used to redefine the landscape boundary to encompass the most critical habitat under legal protection.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

SA designed and conceptualized the research collected relevant data, analyzed data, and wrote the draft manuscript.

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Conflict of interest

Author SA was employed by GFA Consulting Group.

Publisher's note

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