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Prioritizing forest conservation strategies using a multi-attribute decision model to address concerns with the survival of the endangered dragon tree (*Dracaena ombet* Kotschy and Peyr.)

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ABSTRACT

The globally endangered *Dracaena ombet* is one of the ten dragon multipurpose tree species in arid ecosystems. Anthropogenic and natural factors are now impacting the sustainability of the species. This study was conducted to prioritize criteria and alternative strategies for conservation of the species using the Analytical Hierarchy Process (AHP) model by involving all relevant stakeholders in the Desa'a dry Afromontane forest, northern Ethiopia. Information about the potential alternative strategies and the criteria for their evaluation were first collected from experts, personal experiences and literature reviews. Afterwards, they were validated using stakeholders' focus group discussions. Five candidate strategies with three evaluation criteria were considered for prioritization using the AHP techniques. The overall priority ranking value of the stakeholders showed that the ecological criterion was deemed as the most essential factor for the choice of the alternative strategies, followed by the economic and social criteria. The minimum cut-off strategy, combining exclosures with collection of only 5% of plant parts from the species, soil and water conservation and habitat protection management options, was selected as the best alternative strategy for sustainable *D. ombet* conservation. The livelihood losses due to the selected strategy should be compensated by the collection of non-timber forest products, poultry farming, home gardens, rearing small ruminants, beekeeping and agroforestry. This approach may be extended to study other dragon tree species and explore strategies for the conservation of other arid ecosystems.

1. Introduction

Ethiopia has a total area of 1.1 million square kilometres, (FAO, 2010), of which nearly 15.5% is covered with forests, including high forests, shrubs and scrub lands (MEFCC, 2016). The Ethiopian forests are diverse and provide substantial economic and ecological benefits. The former, in 2015, were estimated to be $4.6 billion, contributing to 3.8% of the country's national gross domestic product (UNEP, 2016). However, the forest unsustainable use have led to rapid decrease in area cover, biodiversity, economic production and ecosystem functions (Taddese, 2001; Gebremedhin et al., 2003; Naritaa et al., 2018). In this framework, fifty-eight national forest priority areas have been identified and designated for sustainable conservation of biodiversity resources (Woldemichael, Bekele, & Nemomissa, 2011). The Desa'a forest, located

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in northern Ethiopia, is one of the priority areas for conservation. It encompasses high valued endemic, locally and globally threatened species such as *Erica arborea*, *Dracaena ombet* and *Emberiza cineracea* (Aynekulu, 2011).

Dracaena ombet Kotschy and Peyr. (*D. ombet*), also known as Nubian dragon tree, is grouped in the *Dracaena* genus and the *Asparagaceae* family (Brown & Mies, 2012). Among the *Dracaena*, the dragon tree group that comprises 10 tree species including *D. ombet.* These species are characterized by an arborescent growth habit with stout trunks and broad-based leaves, closely packed leaves at branch apices, thick cuticle on the leaves, high water use efficiency and drought adaptability (Marrero et al., 1998; Madera et al., 2020). The trees can survive in a wide range of geographical areas, are one of the basis for life in arid ecosystems with substantial economic, ecological and social values (Ghazali et al., 2008; Habrova et al., 2009; Hubulkova, 2011; Al-okaishi, 2020). However, these ecosystems are now degraded by over-exploitation, overgrazing, habitat fragmentation and climate change (Hubulkova, 2011; Al-okaishi, 2020; Madera et al., 2020). As a consequence, of the ten dragon trees (Wilkin, Suksathan, Keeratikiat, & Welzen, 2012), five of them - *D. ombet, D. cinnabari*, *D. tamaranae*, *D. draco* and *D. serrulata* - have already been included in the International Union for Conservation of Nature (IUCN) Red List as threatened tree species (IUCN, 2017).

D. ombet may currently be found in the bushland or woodland forms in the mountainous slopes and cliffs of Egypt, Sudan, Ethiopia, Eritrea, Somalia, Djibouti and Saudi Arabia (Bos, 1998; Ghazali et al., 2008; Aynekulu, 2011). Typically, it is found in areas with altitude between 1000 and 1800 m with annual rainfall of 50–530 mm (Kamel et al., 2014; WeForest, 2018). The tree is used as a source of livelihood for many locals through the harvest and use of its plant parts for making ropes, beehives, mats and other household utensils (Ghazali et al., 2008; WeForest, 2018). It is also valued for livestock feed, medicine, soil and water conservation, carbon sequestration and adaptation to the impacts of climate change (Ghazali et al., 2008; Kamel et al., 2014; Mohammed, 2015; WeForest, 2018; Madera et al., 2020). Despite the species wide values, it is now heavily impacted by anthropogenic and natural factors. For example, in northern Ethiopia, it is found with low density (200 ha^{-1}) and unstable population structure with lack of regeneration due to overexploitation and habitat degradation (Gidey et al., unpublished data). The same structural problems are reported in Egypt (El azzouni, 2003; Ghazali et al., 2008; Elnoby et al., 2017) and Sudan (Mohammed, 2015). As a consequence, Kamel et al. (2014) suggested the species to be updated to the critically endangered category on the IUCN Red List from its current endangered status (IUCN, 2017).

D. ombet's health and population status in Ethiopia is currently threatened by overexploitation, habitat destruction and climate change (Aynekulu, 2011; WeForest, 2018; Lengalova et al., 2020). The lack of clear property rights and competing stakeholder interests in some *D. ombet* areas also complicate the implementation of conservation strategies. The local communities need to harvest the species to support their livelihood whereas the local NGOs emphasize its conservation (WeForest, 2018). Promoting consensus between the stakeholders is influential to ensure the acceptability of conservation policies for the species conservation (Negussie & Delaet, 2017). The Analytical Hierarchy Process (AHP) model is a multi-attribute decision tool that offers a framework to accommodate these conflicting interests through pairwise comparisons (Saaty, 2010). To accomplish this, the overall goal/objective is placed at the top level in the hierarchical structure of a decision tree, followed by criteria at the second level helping with the definition of the alternative strategies that are placed at the bottom of the structure (Masozera et al., 2006; Mendoza & Martins 2006). Selected individual stakeholders are then asked to compare among all the elements at a particular level, considering the elements located in a level above by using the pairwise comparison matrices of AHP (Saaty, 2010). The comparisons made by individuals at different levels are finally combined to produce a final priority value for the alternative strategies at the bottom of the hierarchy, according to their importance to the overall objective (Saaty, 2010). The AHP model has already been used in prioritization of conservation alternatives for threatened plant species (Abiyu et al., 2006; Dhar et al., 2008; Derero et al., 2018; Gidey et al., 2020) and forest conservation (Sheppard & Meitner, 2005; Masozera et al., 2006; Mendoza & Martins, 2006; Balana et al., 2010; Jalilova et al., 2012; Lepetu, 2012). Nevertheless, there is little experience in use of AHP in Ethiopia even though it is a helpful approach to generate consensus and minimize conflicts among stakeholders in the framework of the development of policies targeting the conservation of endangered species (Abiyu et al., 2006; Gidey et al., 2020). This research addresses this knowledge of gap. It addresses the objectives: i) developing alternative strategies and their evaluation criteria for *D. ombet* conservation; ii) prioritizing criteria options for the alternative strategies; and iii) prioritizing the alternative strategies for sustainable *D. ombet* conservation using AHP techniques by involving all relevant stakeholders.

2. Methods

2.1. Study area

Desa'a dry Afromontane forest (13° 20′–14° 10′N; 39° 32′–39° 55′E) is located in northern Ethiopia, on the border between the highland of Tigray and lowland Afar regions (Fig. 1). It is one of the few significant remnants of the dry Afromontane forests, and is among the 58 national forest priority areas designated to conserve biodiversity resources (Woldemichael et al., 2011). The Ethiopian government selected it as one of the biodiversity hubs for implementing the international climate change mitigation policy through the $REDD^{+}$ program (Tetemke et al., 2019). It provides several ecosystem services and it supports the livelihood of nearly a half million people (WeForest, 2018).

Deas'a covers about 154,000 ha with elevation ranges from 3100 m in the highlands to 900 m in the lowlands (WeForest, 2018). The average annual temperature and precipitation range between 13 and 25 °C and 400 to 700 mm, respectively (Hishe et al., 2021). The climate of the forest is influenced by topography and exposure to rain-bearing winds (Nyssen, Vandenreyken, & Poesen, 2005). The forest is mainly made up of Precambrian basement in northern landscapes and Hintalo limestone and Adigrat Sandstone in southern areas (Williams, 2016). The dominant soil types are Leptosols, Cambisols, Vertisols, Regosols and Arenosols (BoANR, 1997). The slopes are characterized by plane to steep frequently dissected by stream incisions. The variability in climate, elevation, topography and soil make the forest to be home for diverse flora and fauna species, of which several are endemic to Ethiopia (Aynekulu, 2011). The forest is also an important habitat for threatened tree species including *D. ombet* and *D. glabra* (Aynekulu 2011). *D. ombet* co-exists with the *Acacia etbaica* communities on stony and eroded areas, at elevation between 1000 and 2000 m in the forest (Aynekulu 2011, Personal observation). *Juniperus procera* and *Olea europaea* subsp. *cuspidata* are the dominant species of Deas'a forest, forming a dry and evergreen Afromontane landscapes (WeForest, 2018). The forest is now subjected to strong deforestation pressures by overexploitation, illegal cutting, agricultural expansion, climate change and encroachment by expansive shrubs despite its substantial values (Aynekulu, 2011; Negussie & Delaet, 2017; Haile et al., 2021; Hishe et al., 2021).

2.2. Development of criteria and alternative strategies

This study used the AHP approach to select the best strategy for *D. ombet* conservation while considering economic, ecological and social aspects as perceived by relevant stakeholders. All candidate alternative strategies for the species conservation were first developed by consulting experts, personal field experiences and systematic literature reviews (e.g., El azzouni, 2003; Ghazali et al., 2008; Aynekulu, 2011; Elnoby et al., 2017; Lengalova et al., 2020). Similar procedures were followed for the development of the criteria to evaluate the strategies. The

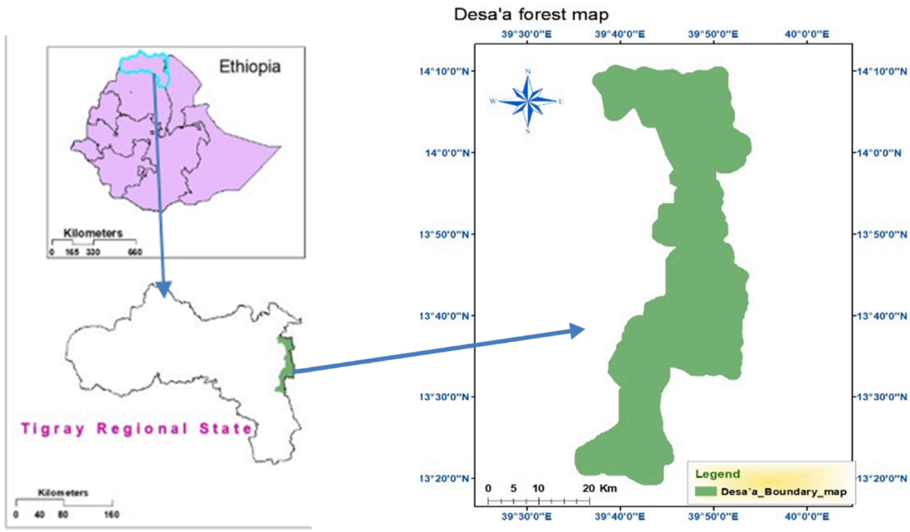

Fig. 1. Geographic location of Desa'a forest in Ethiopia.

alternative strategies and their evaluation criteria were then critically evaluated and validated using focus group discussions that encompassed 15 representative stakeholders. This included five key informants from the local community, the NGOs and the forest experts to ensure the representation of different interests on the species. This participatory process built from the experience reported in the literature (e.g., Masozera et al., 2006; Balana et al., 2010; Lepetu, 2012; Gidey et al., 2020). The representatives were informed about the study before a joint workshop in order to have similar understanding of its objectives. They met afterwards in the two days' workshop at the Agulae town, located near to the study area. In the workshop, the representatives freely exchanged their opinions to define alternative *D. ombet* conservation strategies and the criteria to be used for its evaluation.

2.3. Comparison of criteria and alternative strategies

Data on the prioritization of the proposed criteria and the alternative strategies for the species conservation were collected using a structured questionnaire. The questionnaire was first developed using the hierarchical structure (Fig. 3) for pairwise comparisons using the AHP matrices (Table 1) (Saaty, 2010). Secondly, it was answered by 30 representative individuals selected from the three stakeholder groups - local community, NGOs and forest experts, participating in the focus group discussions. From each group of stakeholders, ten representative individuals were selected in order to ensure that each group had equal representation. Individuals who participated in the focus group discussions were not re-selected to minimize biases (Balana et al., 2010; Lepetu, 2012; Gidey et al., 2020). Ahead of the comparison activities, the questionnaire respondents were briefed about the study, the alternative strategies as well as the criteria to evaluate them as provided by the focus groups. In the two days' workshop held in the Agulae town, each individual used the questionnaire to make pairwise comparisons

Table 1
The Analytical Hierarchy Process (AHP) pairwise comparison scales.

Intensity of relative importance	Definitions
1	Equal importance
3	Weak importance of one over the other
5	Strong importance of one over the other
7	Very strong importance one over the other
9	Absolute importance of one over the other
2,4,6, and 8	Intermediate values between two adjacent judgements

for all possible pairs of elements. The alternative strategies were compared to each other with respect to each criterion above it, and the criteria were compared to each other with regard to the overall objective (Fig. 3).

The comparisons were made on a scale from 1 (the two elements are equally essential) to 9 (the ultimate significance of one factor over the other), with several intermediate values (Table 1) (Saaty, 2010). The eigenvalue technique was used to calculate the relative weight of each element within each category (e.g. the alternatives within each criterion). To use this method, a reciprocal matrix must be built, and the eigenvalue and relative weight of each member must be calculated using a formula from Saaty (2010).

The pairwise comparisons are used to construct a reciprocal matrix of weights. If w_n is an assigned weight to an item, and n is the number of items compared through pairwise comparisons, the reciprocal matrix A is constructed by assigning to any a_{ij} element the corresponding relative weight and placing on the opposite side of the main diagonal the reciprocal relative weight $a_{ji} = 1/a_{ij}$ as showed in Equation (1).

$$A = a_{ij} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \tag{1}$$

In the matrix, when $i = j$, then $a_{ji} = 1$. When matrix A is multiplied by the transpose of the vector of weights w, we get the resulting vector in nw,

$$Aw = nw \tag{2}$$

Where $w = (w_1, w_2, \cdots\cdots..w_n)^T$ and n is the number of rows or columns. Equation (2) can be rewritten as:

$w = (w_1, w_2, \ldots, w_n)^T$ and n is the number of rows or columns. Equation (2) can be rewritten as:

$$(A - nI)w = 0 \tag{3}$$

Where n is also the largest eigenvalue, λ_{max}, or trace of matrix A and I, is the identity matrix of size n. Saaty (2010) suggested that $\lambda_{max} = n$ is a necessary and sufficient condition for consistency. However, when the pairwise comparisons are based on human responses, inconsistency may occur, leading λ_{max} to deviate from n. Therefore, the matrix A has to be tested for consistency using the equations:

$$CI = (\lambda max - n)/(n - 1), \quad (4)$$

$$CR = CI/RI \quad (5)$$

Where CI is the consistency index, RI is the random index *(RI)* generated for a random matrix of order n, and CR is the consistency ratio (Saaty, 2010). A high CR means high inconsistency within the matrix of pairwise comparisons. As a rule-of-thumb, CR value should be lower than 0.1 to maintain consistency of the matrix (Masozera et al., 2006; Saaty, 2010).

Once all the elements were compared and weighted using the eigenvalue method by each individual representative, the geometric mean was used to aggregate and average results of the 30 individual representatives in order to produce the overall relative priority ranks for each criteria or alternative strategy (Saaty, 2010). The Expert Choice computer software (Expert Choice, 2009) was used to analyse the pairwise comparisons (weights), the overall relative priority ranking values and the CR values.

3. Result and discussion

3.1. Developed criteria and alternative strategies

During the focus group discussions, stakeholders identified livestock grazing, illegal cutting, leaf defoliation, stem debarking, erosion and expansive shrubs encroachment as the most important threats to the species (Fig. 2) and to the development of conservation strategies. Moreover, the stakeholders reached an agreement on the conceptual hierarchical structure of the study, and on the five alternative strategies for *D. ombet* conservation with their three evaluation criteria (Fig. 3). They also defined different characteristics for each alternative strategy (Table 2) by considering the species' existing conservation threats (Fig. 2). The first alternative strategy consisted of "business as usual" (0). It encompassed the current practices: free grazing, illegal cutting, leaf defoliation and stem debarking. It did not include any soil and water conservation (SWC) or habitat protection management options (Table 2). The second alternative was the "no cut-off strategy" (I), featuring the introduction of exclosures along with no cutting, defoliation and debarking of the species. It also comprised the introduction of SWC and species habitat protection management options. The third alternative, the "minimum cut-off strategy" (II) considered the introduction of exclosures combined with only 5% of cutting, defoliation and debarking of each individual tree. The "intermediate cut-off" (III) and the "maximum cut-off" (IV) strategies, considered also exclosures along with different cutting, defoliation and debarking levels: 15% and 25% in the case of the III and the IV strategies, respectively. The II, III and IV strategies also considered the introduction of SWC and species habitat protection management options (Table 2). The three criteria to evaluate the strategies encompassed economic, ecological and social aspects (Fig. 3). The economic criterion considered the roles of the candidate strategies in improving and sustaining the species contribution to the livelihoods of the local community. The ecological criterion looked at the contribution of the strategies to ecological functions (e.g., regeneration, erosion control). The social criteria emphasized the roles of the strategies on the sustainability of the species' medicinal and aesthetic values.

The stakeholders fully agreed during the focus group discussions on the introduction of exclosures into the species' habitats. The observation of impacts of the current free grazing as well as research suggestions (Abiyu et al., 2006; Giday et al., 2018) highlighted the need to exclude livestock grazing. The stakeholders also agreed on the introduction of a bench terrace type of SWC, as widely practiced in northern Ethiopia (Negussie & Delaet, 2017), to be introduced in the degraded habitats of the species. Furthermore, the habitat protection management options focused on minimizing the impacts of encroachment by shrubs such as *Cadia purpurea* and *Tarchonanthus camphoratus* on the specie and its habitats (Haile et al., 2021).

3.2. Prioritization of the criteria

All stakeholder groups ranked the ecological criterion (with a

Fig. 2. Different threats of *D. ombet* and its habitats in Desa'a forest: A) Stem cutting, B) Stem debarking, C) Leaf defoliation, D) Overgrazing, E) Erosion and F) Encroachment by expansive shrubs.

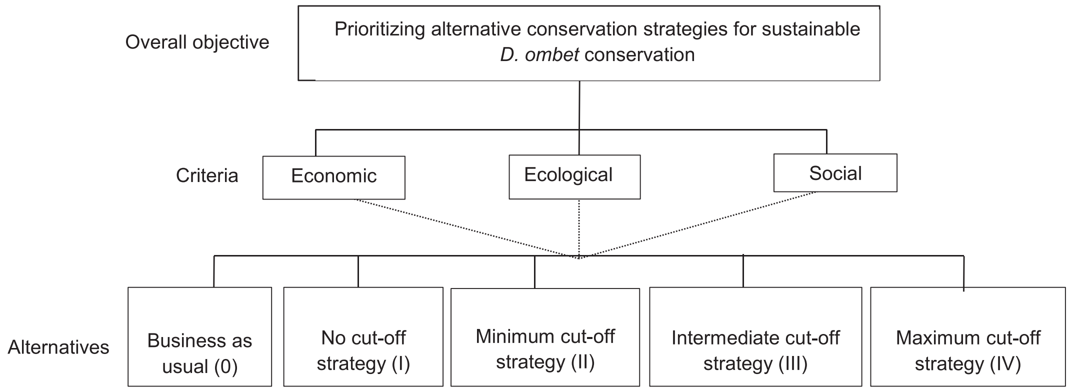

Fig. 3. Hierarchical structure of Analytical Hierarchy Process (AHP) model for *D. ombet* conservation.

Table 2
Characteristics of the five alternative strategies for *D. ombet* conservation.

Characteristics	Alternative strategies				
	Business as usual strategy(0) (%)	No cut-off strategy (I)	Minimum cut-off strategy(II) (%)	Intermediate cut-off strategy(III) (%)	Maximum cut-off strategy(IV) (%)
Stem cutting	40	No	5	15	25
Leaf defoliation	40	No	5	15	25
Stem debarking	40	No	5	15	25
Area exclosures	No	Yes	Yes	Yes	Yes
Soil and water conservation	No	Yes	Yes	Yes	Yes
Habitat protection	No	Yes	Yes	Yes	Yes

relative priority weight of 0.491) as the most important factor pertaining to the choice of the candidate strategies for sustainable *D. ombet* conservation (Table 3). The stakeholders explained in the group discussion that natural regeneration of the species has not been seen in the area for more than a decade. They considered overgrazing and overexploitation of the species as the key reasons for the absence of natural regeneration. They therefore embraced conservation initiatives by giving high importance to their ecological roles in order to preserve the species, notably to enhance regeneration capacity and seedling growth. Additionally, for the purpose of prioritizing the different strategies, the stakeholders ranked the economic criterion (0.328) as the second most important, followed by the social criterion (0.181) (Table 3).

Table 3
Stakeholders' relative priority ranking values for *D. ombet* conservation alternative strategies with respect to criteria, with a Consistency Ratio value of 0.08.

Criteria	Alternative Strategies	Priority (all stakeholders)	Relative priority weight
Economic	0	2	0.100
	I	5	0.010
	II	4	0.031
	III	3	0.065
	IV	1	0.122
			0.328
Ecological	0	5	0.040
	I	1	0.150
	II	2	0.124
	III	3	0.101
	IV	4	0.076
			0.491
Social	0	5	0.011
	I	3	0.030
	II	1	0.080
	III	2	0.040
	IV	4	0.020
			0.181

0 = business as usual strategy; I = no cut-off strategy; II = minimum cut-off strategy; III = intermediate cut-off strategy; IV = maximum cut-off strategy.

The stakeholders' preferences regarding the alternative strategies, based on ecological, economic and social criteria, are consistent with previous studies. For example, exclosure, namely the exclusion of livestock grazing, was selected as the best in-situ conservation *D. ombet* action against other alternatives in Gabel Elba, northern Egypt (Ghazali et al., 2008). Gidey et al. (2020) also ranked the ecological factor as a top priority, followed by economic and biological criteria for *Boswellia papyrifera* conservation in northern Ethiopia. As part of a joint application of population viability risk management (PVRM) and AHP techniques, different ecological, economic and social parameters were also used to prioritize six alternative strategies for *B. papyrifera* conservation (Abiyu et al., 2006). In addition, local ecological knowledge was used for the development of a multi-criteria decision support tool for selection of multi-purpose trees to rehabilitate highly degraded northern Ethiopian highlands (Reubens et al., 2011). Accommodating diverse ecological, economic and social interests of stakeholders through mutual consensus was further mentioned as an effective approach for sustainable conservation of forests (Sheppard & Meitner, 2005; Masozera et al., 2006; Balana et al., 2010; Jalilova et al., 2012; Lepetu, 2012).

3.3. Prioritization of the alternative strategies

The study highlighted the relative priority rankings of the candidate alternative strategies for *D. ombet* conservation by all stakeholders and each stakeholder group (Fig. 4). Results indicated that strategy II (0.478) was the preferred alternative for sustainable *D. ombet* conservation, followed by strategies III (0.232) and IV (0.152). On the contrary, strategy I (0.091) and 0 (0.047) were less suitable alternatives (Fig. 4). Some differences were observed among the stakeholder groups during the focus group discussions. The local community ranked strategy IV (0.331) as the best alternative while the NGOs and the forest experts chose strategies I (0.303) and II (0.411), respectively (Fig. 4). During the discussions, stakeholders expected that traits of the selected strategy II (Table 2) would improve viable seed production, natural regeneration,

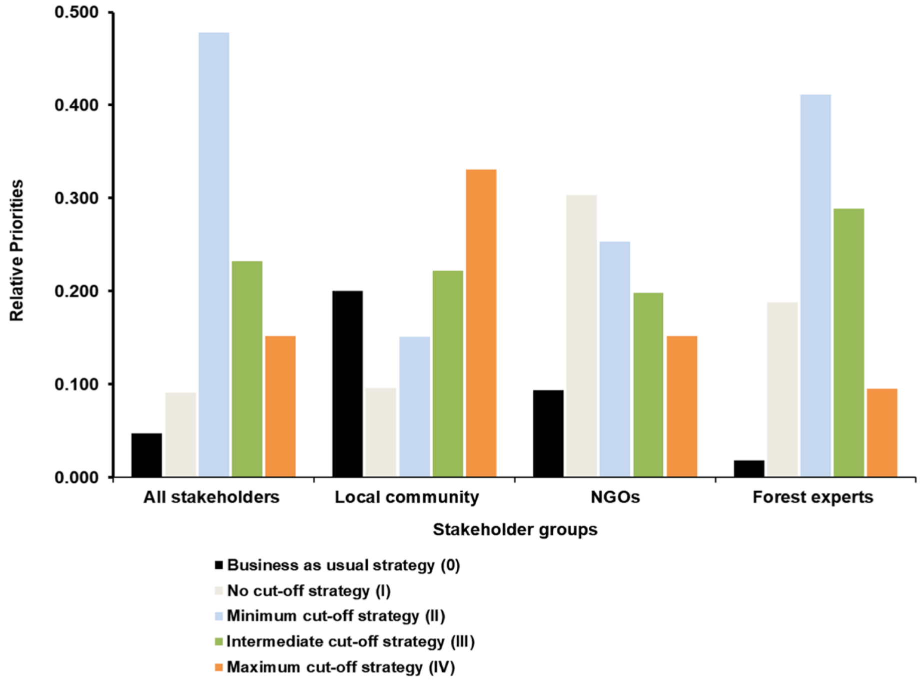

Fig. 4. Relative priority values of the stakeholder groups for *D. ombet* conservation alternative strategies, with a Consistency Ratio value of 0.08.

seedling growth and habitat restoration of the species by improving soil conditions whereas reducing disturbances such as browsing pressure and soil erosion. One fact raised by stakeholders in the discussions was that the introduction of strategy II would reduce the support provided by the species to their current livelihood. To compensate for this, other available contribution to the communities livelihoods were suggested, for example, the collection of non-timber forest products (NTFP) (e.g., medicinal plants), poultry farming, home gardens, rearing of small ruminants (e.g., sheep), beekeeping and agroforestry. This is consistent with findings by research of the contribution of non-wood products to the bioeconomy in other areas (e.g. Ghazali et al., 2008; Huber et al., 2023). In addition, stakeholders expressed the need for extensive technical skills training on the alternative resource management options prior to their introduction. The stakeholders also proposed the introduction of a cut-and-carry system (e.g., grass) and its fair distribution mechanisms to compensate for the expected reduction in grazing lands as a consequence of strategy II.

The selection of strategy II as the best alternative for *D. ombet* conservation (Fig. 4) reflects the importance of excluding livestock grazing (Table 2). Overgrazing is the major cause of mortality for *D. ombet* seedlings, and setting up exclosures is a critical step in improving the availability of viable seeds for regeneration, the vitality of the emerged seedlings. This is influential for the restoration of this species and other dragon trees (Vetaas, 1993; El azzouni, 2003; Ghazali et al., 2008; Elnoby et al., 2017;Almeida & Censo, 2003; Al Hosni et al., 2018; Madera et al., 2018; Lengalova et al., 2020; Vahalik et al., 2020). This is consistent with the findings by Habrova & Pavlis (2017) that without grazing exclosure, the availability of natural regeneration for *D. cinnabari* and other woody species on the island of Socotra in Yemen is almost impossible. Because young trees of *D. cinnabari* are slow growers, any reforestation effort must be accompanied by adequate and substantial fencing over a long period (Madera, Volarik, Patocka, Halivodova, & Divin, 2019). The continued exclusion of goats has been strongly recommended to reduce mortality of *D. cinnabari* seedlings on the island of Socotra (Madera et al., 2018). Such results are also consistent with other studies on endangered species, e.g., Abiyu et al. (2006) and Gidey et al. (2020) proposed a grazing exclusion strategy to improve regeneration and seedling development in *B. papyrifera* forests in northern Ethiopia. *B. papyrifera* forests under exclosures offered more viable seeds, a stable population and higher regeneration compared to forests under non-exclosures (Tilahun et al., 2011; Alemu et al., 2012; Eshete et al., 2012; Negussie et al., 2018). In addition, the exclusion of grazing for the sustainable conservation of forests and their valuable species has been strongly suggested elsewhere (Giday et al., 2018; Madera et al., 2020).

The other important feature of strategy II was to allow the collection of only 5% of plant parts of *D. ombet* for subsistence purposes, far less than the current practice which is around 40% (Table 2). This practice would help to preserve mature trees of the species for the production of viable seeds and reduce insect and disease damage. Overcutting the trunk, bark and leaf of *D. ombet* accelerated its regeneration failure and population decline (El azzouni, 2003; Ghazali et al., 2008; Kamel et al., 2014). These practices also resulted in lower regeneration, higher seedling mortality and unstable population structure for *D. cinnabari* (Edward et al., 2001) and *D. serrulata* (Lavranos, 2017; Vahalik et al., 2020). Nevertheless, collecting just 5% of the tree's plant parts would impact the livelihood of local communities. The current initiatives of the WeForest Foundation in the Desa'a forest address the challenge of finding alternative resource management options to compensate for this loss. The foundation provided alternative livelihoods such as poultry, small ruminants, beekeeping and vegetable seeds to the local communities to reduce their encroachment on the forest for economic reasons (WeForest, 2018). Mushroom production, ecotourism and *Aloe vera* gathering could also provide alternative livelihoods for local communities from the forest (WeForest, 2018). These alternative livelihoods are practised elsewhere. For example, planting vegetables and medicinal plants in home gardens on the island of Socotra as alternative livelihoods against the overexploitation of *D. cinnabari* for resin is shown to make some positive contributions to conserving the archipelago's biodiversity (Ceccolini, 2002; Novakova, 2015). Collections of aloe juice, frankincense and honey have also been used as alternative livelihoods on this island (Madera et al., 2019). Additionally, the over-tapping of *B. papyrifera* for frankincense is a major threat to its sustainability in northern Ethiopia, and it has been strongly recommended that this practice to be phased out for at least 5–10 years. The associated livelihood losses have then been proposed to be compensated through NTFP collection, poultry farming, home gardens and beekeeping (Lemenih & Kassa, 2011; Gidey et al., 2020).

The introduction of SWC management options is one of the features of strategy II (Table 2). The dry Afromontane forest of Desa'a, which is a habitat of the species, is now severely degraded by erosion, overgrazing, drought and encroachment of extensive shrubs (Aynekulu, 2011; Giday et al., 2018; Haile et al., 2021). The introduction of SWC management options may contribute to ecological restoration by enhancing soil fertility and soil moisture while minimizing erosion and runoff (Mekuria et al., 2009; Negussie & Delaet, 2017). SWC management options may also contribute to ecological restoration of *D. ombet* in Gebel Elba, northern Egypt, as the species grows in a shallow soil with no permanent groundwater (Ghazali et al., 2008). The increase of soil fertility and the reduction of soil erosion through land conservation techniques improved growth of *D. cinnabari* seedlings (Pietsch, Kuhn, Morris, & Mubarak, 2013). The remaining feature of strategy II is the introduction of habitat protection management options (Table 2), specifically by minimizing the impact of expansive shrubs such as *C. purpurea* on *D. ombet* through appropriate techniques. Sprawling pioneer shrubs are mentioned elsewhere as they compete with slow-growing native species such as dragon trees thus contributing to its decline (Van Damme & Banfield, 2011; Madera et al., 2020; Haile et al., 2021). Once dominated by native *J. procera* and *O. europaea*, the Desa'a forest is now gradually being replaced by invading light-demanding shrubs such as *C. purpurea*, no doubt affecting its future biodiversity composition (Aynekulu, 2011; Negussie & Delaet, 2017; Haile et al., 2021).

Finally, it should be noted that *D. cinnabari*, *D. tamaranae*, *D. draco* and *D. serrulata*, in the group of dragon tree species, have already been listed as globally threatened plant species on the IUCN Red List (IUCN, 2017), are also threatened by livestock grazing, overexploitation and habitat destruction (Wilkin et al., 2012; Lavranos, 2017; Madera et al., 2020). These species can therefore benefit from strategy II, which is the best option in this study for sustainable *D. ombet* conservation.

4. Conclusions

The study involved all relevant stakeholders to develop five alternative strategies and their three evaluation criteria for sustainable *D. ombet* conservation. It also demonstrated the contribution of the AHP approach in prioritizing these alternative strategies by engaging multiple stakeholders with their competing interests through the promotion of the negotiation of conflicting interests. The study showed that the ecological criterion was the most important factor to choose from the alternative conservation strategies. Furthermore, the study suggested that the minimum cut-off strategy, combining exclosures, collection of only 5% plant parts of the species, SWC and habitat protection management options, is the one that most contributes to the sustainable conservation of the species. Livelihood losses due to this strategy should be compensated by NTFP gathering, poultry farming, home gardens, raising small ruminant, beekeeping and agroforestry. This AHP-based approach may be extended to study other dragon tree species and explore strategies for the conservation of other arid ecosystems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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