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# Local ecological knowledge on preferred vegetation of African savanna elephants in the semi-desert highlands of northwest Namibia

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ABSTRACT

The Northern Highlands of northwest Namibia are a particularly remote and arid landscape, where wildlife, habitats and local communities are increasingly at risk from future climate change events. There has previously been minimal research on the population of African savanna elephants (*Loxodonta africana*) in these Highlands. The Highlands are located just to the west of Etosha National Park. One potential factor influencing the movement of elephants from the Park into the Highlands is their food preferences. The aim of this study was to determine the preferred forage species for elephants in the Highlands. The study benefited from local ecological knowledge of community game guards, and extensive field patrols to assess the most preferred trees of elephants. Our findings indicate clear selection preference for African star chestnut (*Sterculia africana*), and *Commiphora* species such as blue-leaved corkwood (*Commiphora glaucescens*). These species grow on steep mountain slopes and elephants are climbing slopes to browse those trees. Our results indicate that some tree species are much less preferred, most of which tend to be located in valleys or lower slopes. This suggests that a major factor in the increase in elephant population in the Northern Highlands is the preferred vegetation available on the mountain slopes compared to the vegetation on the flat landscape of Etosha.

## 1. Introduction

### 1.1. The study area and its elephant population

Northwest Namibia is an extremely arid area, described as desert to semi-desert habitat and characterised by low rainfall (typically 50–200 mm per year) (Namibia Meteorological Service, 2023). The rainy season tends to be from January to March, but usually the rainfall is erratic and unpredictable, and in some years there is no rain in some areas. There have been several droughts in northwest Namibia in the years since 2013 (Sasscal, 2023). The potential risks of climate change in the future include more severe droughts, which would increase competition between humans and wildlife for natural resources in this fragile environment (Zeidler et al., 2013). It has been anticipated that climate change will play a major role in the future stability of this fragile ecosystem, with Southern Africa predicted to warm twice as fast as the global average (Turpie et al., 2010; Niang et al., 2014; WMO, 2021).

The IUCN African Elephant Status Report estimates that the African savanna elephant (*Loxodonta africana*) population in Namibia was about 22,700 in 2016 (Thouless et al., 2016), with a healthy growth rate estimated at 5.4 % since the late 1990s (Craig et al., 2021). Over 80% of the elephant population is located in the northeast of the country, in the Zambezi and Khaudum-Kavango wildlife complex (Fig. 1). Other ranges in Namibia include a population in Etosha National Park and in the Kunene Region, between Etosha and the edges of the Skeleton Coast.

The classification of the African savanna elephant on the IUCN Red List of Threatened Species was amended in 2021 from Vulnerable to Endangered (Gobush et al., 2021). The strategic objectives in Namibia's National Elephant Conservation and Management Plan (MEFT, 2021) include local interventions to protect the elephants and their habitats in northwest Namibia. The Management Plan prioritises research on the factors affecting the movements of elephants in the northwest.

The elephants in the Kunene Region represent about 1.5% of the total elephant population in Namibia, spread over a very large area of at least 41,000 km$^2$ (Thouless et al., 2016). These elephants are living mainly outside National Parks, often in hyper-arid conditions among rural

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farming communities. Their range into areas of as little as 50 mm of annual rainfall has led to the western-most populations being termed "desert elephants", and, since the 1980s, there has been detailed research on the population of desert-adapted elephants (Viljoen, 1987; Viljoen, 1989; Viljoen and Bothma, 1990; Leggett, 2019; Brown and Ramey, 2022). Minimal information has been published on elephants elsewhere in northwest Namibia, which includes the remote, mountainous landscape to the west of Etosha National Park that is referred to locally as the Northern Highlands (Fig. 1). When considering the distribution of elephants across Namibia, there are no other areas with rugged and mountainous terrain, except for a small population of desert-adapted elephants which occasionally use parts of the Brandberg. The elephant strongholds of Etosha National Park and the Kavango-Zambezi are markedly flat terrain.

The Northern Highlands cover about 12,000 km$^2$ (more than half the size of Etosha National Park). The altitude is typically over 1,000m a.s.l. in the valleys, with mountain peaks up to 1,800m a.s.l. The African savanna elephant is usually associated with the flat plains of Africa (Skinner and Chimimba, 2005), but elephants in the Northern Highlands walk up steep mountain slopes; behaviour that might not be associated with a species of such a large size (Wall et al., 2006). The local communities in villages in the Northern Highlands carry out their day-to-day lives alongside this small population of elephants. The rural areas in northwest Namibia have some of the poorest communities in the country (GRN, 2015; Inman et al., 2020), and human-elephant conflict at community water points in the area has been adding to challenges of the local communities (Hunninck et al., 2017; Schnegg and Kiaka, 2018; MEFT, 2021; MEFT/NACSO, 2022; Wenborn et al., 2022a).

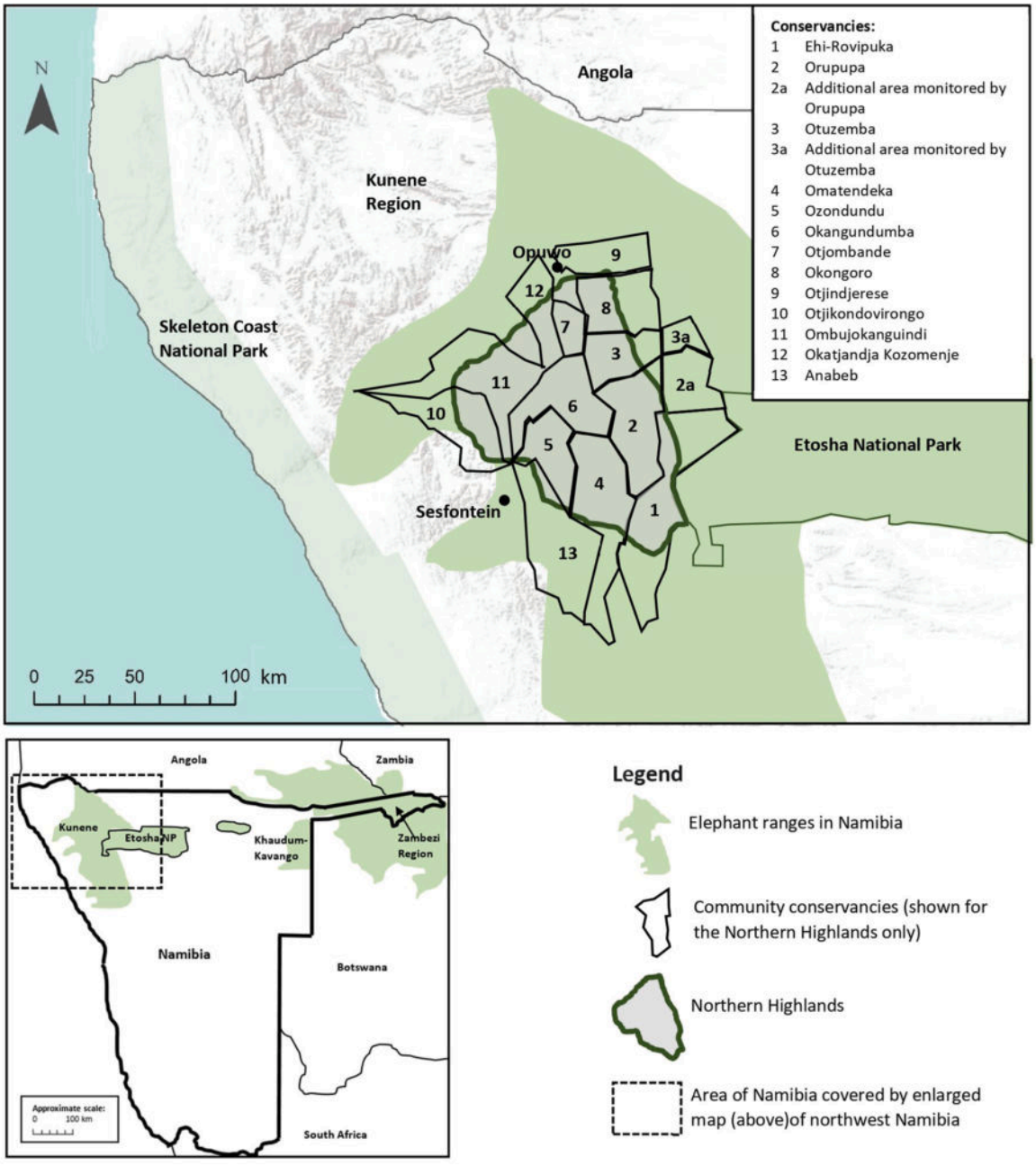


**Fig. 1.** Elephant ranges in Namibia (from the African Elephant Status Report in 2016 by Thouless et al., 2016) and the location of the Northern Highlands in northwest Namibia, showing the community conservancies in the Northern Highlands.

### 1.2. Local ecological knowledge in the Northern Highlands

Local enforcement of conservation laws is difficult in such a remote area, which is one of the reasons why community commitment to wildlife protection is so important. Starting in the 1990s, the community conservancy programme has been implemented in line with the policy of the Government of Namibia, and conservancies now cover a large proportion of the communal land in the northwest, including the Northern Highlands (MEFT/NACSO, 2022). The conservancy model has resulted in improved awareness and higher community commitment to wildlife protection (Boudreaux and Nelson, 2011; Jacobsohn, 2019; Störmer et al., 2019; Wenborn et al., 2022b). The conservancies each typically employ five to ten community game guards, some of whom have had over 20 years of service in their roles. They are responsible for recording wildlife sightings and incidents of human-wildlife conflict in Event Books. Their role also includes raising awareness in communities on the benefits of conservation of habitats and wildlife, in line with the core objectives of the conservancy programme. The game guards have received training from Ministry of Environment, Forestry and Tourism (MEFT) and the main NGOs involved in community-based wildlife conservation in Namibia (Namibian Association of CBNRM Support Organisations (NACSO), World Wide Fund for Nature (WWF) and Integrated Rural Development and Nature Conservation (IRDNC)). The game guards carry out several foot patrols each week, during which they usually do not see elephants, but they will often observe evidence of elephant movements and numbers, such as through footprints, dung and tree species that have been browsed by elephants. The game guards therefore have much useful local ecological knowledge on the elephants in the Northern Highlands, which is potentially useful for research and to inform planning of conservation measures.

Buchholtz et al. (2020) carried out a study on elephants in northwest Botswana, with the conclusions being positive on the use of local expert knowledge to understand patterns of landscape use by elephants. That study noted that people who often interact with elephants, including in situations of human-elephant conflict, do build up ecological knowledge of the species. There had been similar positive conclusions from research on pooling local knowledge and opinions in Cameroon on populations of 33 wildlife species, including elephants, and comparison with field surveys on the ground (Van der Hoeven et al., 2004).

### 1.3. Potential factors influencing the movement of elephants into the Northern Highlands

Local feedback during our scoping activities for this study indicated that elephant numbers have been increasing in the Northern Highlands and that some elephants have moved back into the Highlands from Etosha National Park (Wenborn et al., 2022a). In the times of conflict and droughts in the 1970s and 1980s in the northwest, it was considered that elephants tended to stay in Etosha National Park because of the better enforcement of wildlife protection and the better water availability in the Park (Owen-Smith, 2010; Schnegg and Kiaka, 2018; MEFT, 2021). The enforcement of conservation laws and the attitudes of local people in northwest Namibia outside the Park have strengthened since 1990, and there is now minimal poaching (MEFT/NACSO, 2022). The availability of water resources is also an important factor influencing the return of elephants to the Northern Highlands. The number of community water points has increased since 1990, and the government and development NGOs have stepped up programmes over the last decade to upgrade community water points (MEFT, 2021). This involves installation of solar pumps and replacing diesel pumps at boreholes, resulting in water being more permanently available to communities and also to elephants at the water points. Another factor potentially influencing elephant movements in the Northern Highlands is the type of vegetation species associated with the mountain landscape.

### 1.4. Elephant foraging behaviour

The feeding habits of African savanna elephants have been widely studied. They require large quantities of vegetation, with adult elephants typically eating about 130–150 kg/day (Haynes, 2012). Processing this substantial quantity of biomass means that they are able to tolerate lower plant nutrient levels than most smaller herbivores (Marston et al., 2020). The diets of elephants vary on a seasonal basis, as they seek moisture and nutrients from the tissues in the vegetation (Haynes, 2012; Henley, 2019). In the rainy season, they graze more on fresh grasses and browse fresh leaves. They eat woody vegetation (twigs, branches and bark) in the dry season when the grasses have dried out, and they also eat fruits, pods and roots (Roever et al., 2012; Tsalyuk et al., 2019; Leggett, 2019; Thompson, 2019; Marston et al., 2020). Elephants often strip bark from branches for the sugars and moisture (Haynes, 2012). In a detailed study on selective feeding of elephants in Botswana, Owen-Smith and Chafota (2012) concluded that in the dry season elephants consume a wide variety of vegetation species, whereas in the rainy season, when food availability is relatively high, they are highly selective in terms of the vegetation species that they prefer. Buchholtz et al. (2020) concluded that elephants have a strong preference for a few tree species, and but do browse non-specifically on a variety of plant species.

### 1.5. Vegetation in the Northern Highlands

The distribution of tree and shrub species in Namibia is well documented (NBRI, 2005; Le Roux and Müller, 2018). Many of the species of trees and shrubs in the Northern Highlands are associated with the mountain topography and tend to be less abundant in Etosha National Park. For example, the African star chestnut (*Sterculia africana*) and several species of *Commiphora* are associated with mountain landscape of the northwest, and absent from much of Etosha National Park (NBRI, 2005; Le Roux and Müller, 2018).

Fig. 2 provides a typical example of the variation in woody vegetation of the Northern Highlands landscape, in which the trumpet thorn (*Catophractes alexandri*) and mopane trees (*Colophospermum mopane*) are abundant in the valley and shallow slopes respectively, and the species associated with steeper slopes are on the top part of the hill and the rocky outcrops (e.g. African star chestnut (*Sterculia africana*), blue-leaved corkwood (*Commiphora glaucescens*), purple-stemmed corkwood (*Commiphora multijuga*)).

### 1.6. Rationale and objectives of the research study

Improved wildlife protection and perennial water availability are now common both to Etosha National Park and the neighbouring Northern Highlands. A driver for the increased movement of elephants from the Park into the Northern Highlands could potentially be the presence of preferred forage available in the Highlands compared to Etosha, and in particular the tree species associated with the mountain slopes. It is important for research on elephant movements to identify whether there are specific tree species that might be a factor influencing the movement of elephants from Etosha to the Highlands and also their movement up the mountains. The research on the desert-adapted elephants, to the west of the Highlands, has included some aspects of vegetation preferences (Viljoen, 1989; Leggett et al., 2003), but there have been no published studies on the preferred vegetation of elephants in the Northern Highlands.

The objectives of this study, therefore, were to (i) determine the preferred forage species for elephants in the Northern Highlands; (ii) assess whether the preferred species are associated with the mountain landscape. This would facilitate assessment of the potential influence of tree species on elephant movements from Etosha National Park. The study was based on the knowledge of community game guards who continually patrol the areas and their observations of elephant foraging

**Fig. 2.** Example of the changes in landscape and vegetation, Okomuhana, Ozondundu Conservancy, January 2023.

activity.

## 2. Method

Most of the Northern Highlands are designated as community conservancies (Fig. 1), with 13 conservancies having all or part of their area within the Highlands (NACSO, 2024). During scoping visits to the Northern Highlands in 2021 and 2022, we identified through consultation and field observations that most of the elephant population and movements to be in the conservancies in the eastern and southern areas of the Highlands. We therefore selected the six conservancies of Ehi-Rovipuka, Orupupa, Otuzemba, Omatendeka, Ozondundu and Okangundumba for the study (Fig. 1). These conservancies contain much of the highlands habitat. The rugged and often inaccessible terrain makes it difficult to track elephants on foot and study their habits in the Northern Highlands. The method for this study therefore focused on the local ecological knowledge of the community game guards. Semi-structured interviews were carried out with 34 game guards from December 2022 to February 2023. The game guards were selected mainly from the highlands areas in the six conservancies, through consultation with, and agreement from, conservancy chairpersons. The interviews included all game guards in Orupupa and Ozondundu, all in the highland area of northern Omatendeka, all in Okangundumba except one game guard in the west of the conservancy where elephants are not commonly observed, the core team of game guards in Otuzemba (excluding trainee game guards that had recently been recruited) and two game guards from the more mountainous part of northern Ehi-Rovipuka.

The 34 game guards had between one and 30 years of experience with a mean of 10.3 years. One component of the consultation with the game guards was related to their patrol observations and knowledge on the preferred forage plants of elephants in the Northern Highlands. Earlier scoping visits to study area in January to April 2021 and February to March 2022 had included identification of the most abundant tree species in the Highlands, as well as species that were potentially preferred by the elephants. Based on the initial discussions with game guards during scoping, and observations in the field, a list of 20 tree species was selected (Box 1). For ease of identification during interviews, A4 cards were prepared with photographs and names in the local Otjiherero language for each of the 20 species (Fig. 3). Interviewees were asked to select the top 5 species (in order) that in their opinion elephants most prefer, and the top 5 species (in order) that elephants least prefer (Fig. 4). The game guards were also asked whether the tree species that they selected are observed to be mainly in the mountains or valleys, or both. The consultation also included more open questions on specific tree species (e.g. *Colophospermum mopane*) and associated elephant behaviour, such as their perception for reasons for the time that elephants spend in the mountains. Another component of the semi-structured consultations involved asking game guards their opinion on 10 statements on a Likert scale of strongly agree, agree, etc. These statements related to the general ecology of elephants in the highlands to support aspects of forage preference.

The time in the study area included 10 field patrols with game guards, each for four to 6 h, in Omatendeka, Orupupa and Ehi-Rovipuka conservancies to observe tree species and evidence of elephant movements in the mountains and valleys, including trees that had been eaten by elephants. It also included 60 shorter walks (about 1 h each) for observations.

Trees that had been partially eaten by elephants could be identified with confidence. Generally, such trees tended to have unusual shapes, such as the stems being larger than the size of crown would imply, indicating that branches had been removed at one time. In some cases branches had been removed and stripped of bark, with the remains left on the ground. In cases where damage was more recent, often elephant dung or footprints were observed in the area of the tree. The main aspect to identify, where a tree appeared to have been damaged by elephants,

**Box 1**
Short-list of 20 tree species for questions to game guards on elephant preferences(includes common name, scientific name and name in local Otjiherero language).

1. Leadwood (*Combretum imberbe*) - Omumborombonga
2. African star chestnut (*Sterculia africana*) - Omuhako
3. Camel thorn (*Vachellia erioloba*) - Omumbonde
4. Mopane (*Colophospermum mopane*) - Omutati
5. Purple-pod terminalia (*Terminalia prunioides*) - Omuhama
6. Sicklebush (*Dichrostachys cinerea*) - Omutjete
7. Sycamore fig (*Ficus sycomorus*) - Omukuyu
8. Blue-leaved corkwood (*Commiphora glaucescens*) - Omutungi
9. Tall common corkwood (*Commiphora glandulosa*) - Omukange
10. Velvet corkwood (*Commiphora mollis*) - Omurenda
11. Purple-stemmed corkwood (*Commiphora multijuga*) - Omuzumba
12. Large sour plum (*Ximenia caffra*) - Omumbeke
13. Herero sesame bush (*Sesamothamnus guerichii*) - Ongumbati
14. Shepherd's tree (*Boscia albitrunca*) - Omutendereti
15. Smelly shepherd's bush (*Boscia foetida*) - Otjinautoni
16. Trumpet thorn (*Catophractes alexandri*) - Omukaravize
17. Kudu bush (*Combretum apiculatum*) - Omumbuti
18. Buffalo thorn (*Ziziphus mucronata*) - Omukaru
19. Kaoko ceraria (*Ceraria longipedunculata*) - Omumbondororwa
20. Velvet raisin bush *(Grewia flava*) – Omuvapu

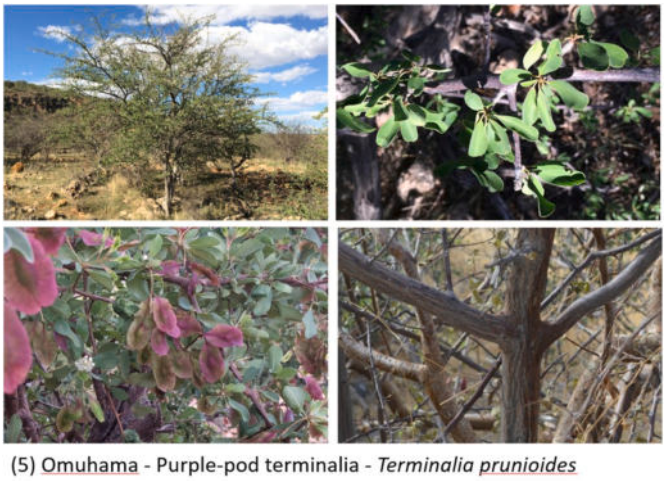


**Fig. 3.** Example of one of 20 cards (A4) of common tree species (*Terminalia prunioides*), from which game guards identified those most and least preferred by elephants.

was whether humans might have cut the tree at some stage, for example for firewood or to clear a vehicle track.

This study, therefore, involved comprehensive consultation to collate local ecological knowledge, combined with verification through extensive observations on the ground.

## 3. Results and discussion

There was a common opinion of game guards that the elephant population has increased. Of the 34 game guards interviewed, 32 (95%) either agreed or strongly agreed with the statement: "the number of elephants in the conservancy has increased in the last 10 years." 25 of 34 (74%) game guards strongly agreed with that statement.

Drivers of elephant movements in the Northern Highlands were attributed to finding food by 16 of 34 game guards (47%), while 13 game guards (38%) identified both food and water as drivers. Additional reasons mentioned in discussion were movement to stay away from people, to go to vegetable gardens and to find sources of salt. When asked about movements at different times of the year, 31 of the 34 game guards (91%) said that one of the main reasons for the movement of elephants was to areas that have had rain and therefore have fresh vegetation. Game guards indicated that elephants have been moving from Etosha to the Northern Highlands in the rainy season. During the consultations, 27 of 34 game guards (79%) agreed or strongly agreed with statement "Elephants used to move into the area from Etosha and go back, but now spend most of their time in the Highlands."

The common feedback from game guards was that elephants eat most of the short-listed plant species (Box 1) when food sources are scarce (e.g. in the dry season or during drought years), in agreement with previous studies (Owen-Smith and Chafota, 2012; Leggett, 2019; Buchholtz et al., 2020). The game guards stated that, in the rainy season when much fresh vegetation is available, elephants are more selective in their choice of browse.

One topic of discussion was on elephant movements to mountains and specifically on the proportion of time spent in mountains or valleys. All 34 game guards observed that elephants spend time in the mountains in the Northern Highlands (Fig. 5). All game guards agreed or strongly agreed with statement: "the main reason that elephants walk up steep slopes is to find their preferred vegetation," with 21 game guards replying "strongly agree" (62%) and 13 replying "agree" (38%).

There are several potential factors influencing the movement of elephants in the mountains. In discussions on elephant movements in the Northern Highlands, 29 of 34 game guards (85%) said that elephants tend to spend more time in the mountains in the rainy season. Game guards attributed this to leaves having sprouted on their preferred tree species, and partly because there is often standing water after rains so they do not need to visit community water points in the valleys. Of the 34 game guards, 24 (71%) said that another reason for time spent in the mountains during rainy season is that elephants stay away from sandy/silt areas in valleys when the ground is wet, because they are concerned about becoming stuck in the wet mud (Fig. 6). Some elephants do spend some time in the valleys, including in rainy season; for example 14 of 34 game guards (41%) said that elephants use the shade of taller riparian trees during the day (Fig. 7). The feedback was that, during the hot season (e.g. October to April), elephants tend to browse in the mountains in the mornings, and move to valleys in the middle of hot days, which


**Fig. 4.** Game guard identifying trees most and least preferred by elephants, Otjapitjapi, Ozondundu Conservancy (at the conservancy office).

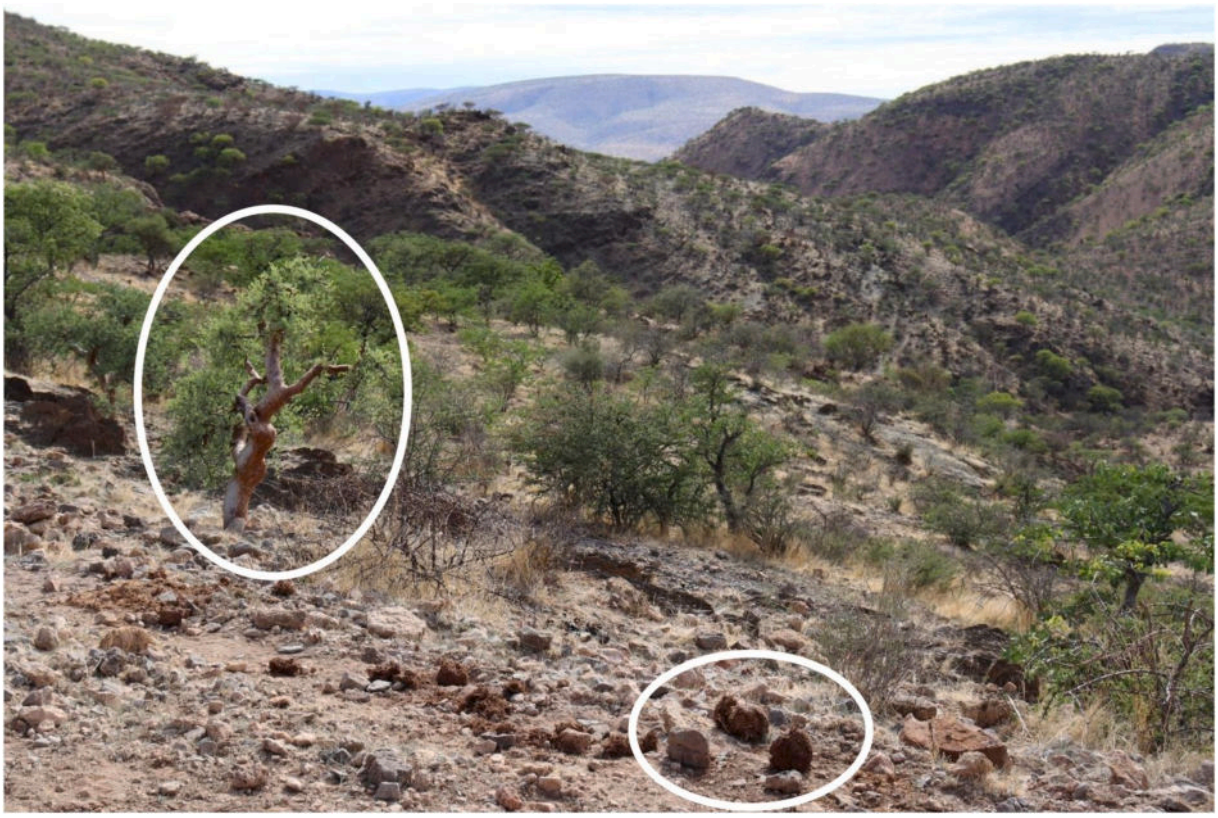

**Fig. 5.** Observations of elephant dung (circled) and trees that had been partly eaten by elephants, such as *Commiphora glaucescens* (circled), were often made during foot patrols on the higher slopes during this study.

**Fig. 6.** Example of deep foot print of elephant in wet valley sand during a period of rains, near Okomuuore, Otuzemba Conservancy, January 2023.

**Fig. 7.** Elephants in the afternoon in March 2022 using the taller mopane trees (*Colophospermum mopane*) in the river bed as shade, near Omuramba, Omatendeka Conservancy. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

concurs with results from previous studies on the movements of the desert-adapted elephants in the area to the west of the Highlands (Leggett, 2019).

The results of the selection of the top five most preferred species (Fig. 8) indicate clear selection for African star chestnut (*Sterculia africana*), *Commiphora* species, mopane (*Colophospermum mopane*) and velvet raisin bush (*Grewia flava*)). *Sterculia africana* was named as no.1 most preferred by nine of 34 game guards (26%), (Table 1). The results also indicate that some species are clearly much less preferred (e.g. smelly shepherd's bush (*Boscia foetida*), shepherd's tree (*Boscia albitrunca*), Herero sesame bush (*Sesamothamnus guerichii*) and leadwood (*Combretum imberbe*)).

It is useful to compare these core results on opinions from game guards with the observations on the ground. In many cases, *Sterculia africana, Commiphora glaucescens, Commiphora multijuga and Colophospermum mopane* were observed to have been partly eaten by elephants (Figs. 9 and 10). It was more difficult to identify whether *Grewia flava* (and the several other *Grewia* species in the area) had been eaten by elephants or other wildlife/livestock, or cut and used by humans. The *Grewia* species tend to be shrubs or smaller trees, whereas the *Sterculia Africana* and *Commiphora* species tend to grow to larger trees, and a partly eaten *Grewia* species cannot always be attributed to elephants.

There were no cases observed during foot patrols where *Boscia foetida, Boscia albitrunca, Sesamothamnus guerichii* or *Combretum imberbe* had been eaten by elephants. The leaves of the two *Boscia* species were observed to be eaten by goats. It is interesting to note that Viljoen, who studied the desert-adapted elephants to the west of the Northern Highlands, including field observations of utilised tree species, concluded that the most important woody food plants for elephants in that area included *Combretum imberbe* (Viljoen, 1989), therefore contradicting the perceptions of most game guards in the Highlands. However, vegetation coverage is much more sparse in that study area than in the Northern Highlands.

Table 1 provides the list of the ten trees that were included the most times in the top five most preferred, for example *Sterculia africana* was named in the top 5 most preferred by elephants by 23 of 34 game guards (68%). The table also shows the perceptions of game guards in terms of whether those trees are located in the mountains, valleys or both mountains and valleys. For example, all 23 game guards that included *Sterculia africana* in the top 5 most preferred stated that these trees are located only in the mountains. These results on trees located in mountainous settings are illustrated in Fig. 11.

Fig. 11 shows that several tree species perceived by game guards as the most preferred by elephants are located at higher elevations in the mountains (e.g. African star chestnut (*Sterculia africana*), blue-leaved corkwood (*Commiphora glaucescens*), purple-stemmed corkwood (*Commiphora multijuga*), and velvet corkwood (*Commiphora mollis*) (Fig. 12). These perceptions were confirmed by observations during surveys on foot. It is interesting to compare these results for the Northern Highlands with abundance of tree species in Etosha National Park, which is largely

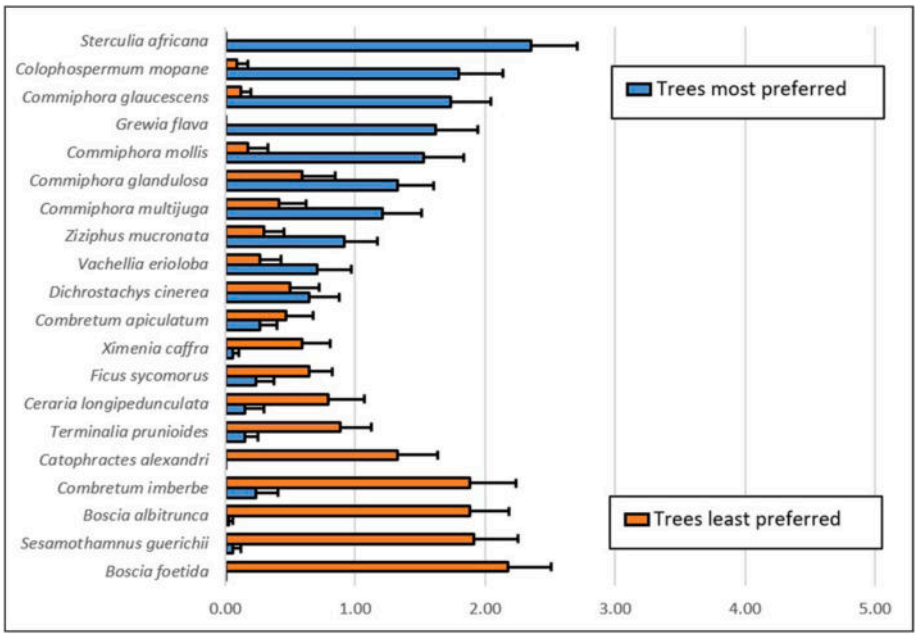


**Fig. 8.** Score (mean + 1 standard error) for the top 5 most preferred and top 5 least preferred tree species of elephants in the Northern Highlands, as identified by game guards (most preferred = 5 points, second most preferred = 4 points, etc.).

**Table 1**
Perception of game guards (n = 34) of location in mountains or valleys of the ten trees that were listed in the top 5 for the most preferred.

| | No. times species named No.1 most preferred | No. times species named in top 5 most preferred | % of game guards who listed the species in top 5 most preferred who said the tree is present in: mountains only/ valleys only/both mountains and valleys |
|---|---|---|---|
| *Sterculia africana* | 9 | 23 | 100/0/0 |
| *Commiphora glaucescens* | 2 | 19 | 100/0/0 |
| *Commiphora mollis* | 2 | 18 | 83/6/11 |
| *Grewia flava* | 4 | 17 | 6/41/53 |
| *Colophospermum mopane* | 4 | 17 | 0/12/88 |
| *Commiphora glandulosa* | 2 | 16 | 38/12/50 |
| *Commiphora multijuga* | 4 | 14 | 100/0/0 |
| *Ziziphus mucronata* | 2 | 12 | 0/75/25 |
| *Dichrostachys cinerea* | 1 | 10 | 0/40/60 |
| *Vachellia erioloba* | 2 | 7 | 0/71/29 |

flat savanna (Fig. 13), with some low hills in the west and south. Etosha National Park has very low abundance of the tree species associated with mountain slopes, but high abundance of *Colophospermum mopane* (NBRI, 2005; Atlas of Namibia, 2022).

Buchholtz et al. (2020) interviewed 25 local experts in northwest Botswana and asked them to select their perception of elephant preferences from 19 species common to that area. Only four of the 19 species were within the 20 species discussed with game guards in our study. The local experts in Botswana identified mopane (*Colophospermum mopane*) and camelthorn (*Vachellia erioloba*) as preferred tree species, which are generally associated with the flatter plains landscape in northwest Botswana. The species associated with the mountain landscape of the Northern Highlands, such as *Sterculia Africana* and several *Commiphora* species, are not common in northwest Botswana and were not included in that study. Unlike the game guards in the Northern Highlands, Buchholtz et al. (2020) found that local experts perceive that elephants do not spend much time in the few hilltop areas of northwest Botswana.

More detailed discussion was carried out with game guards on the habits of elephants in terms of eating mopane trees (*Colophospermum mopane*), which is the dominant tree species in the Northern Highlands, mainly growing in the valleys and lower slopes. Mopane is a deciduous tree that is nutritious (Codron et al., 2007), however, this is interesting because the trees also produce secondary metabolites such as tannins and phenols in their leaves as defence against browsing, particularly in the rainy season when the leaves are green (Cooper and Owen-Smith, 1985; Wessels et al., 2007; MEFT, 2021). Mopane is one of the earliest in flushing its leaves at the end of the dry season (Makhado et al., 2016).

Game guards perceived *Colophospermum mopane* as an important food source (Fig. 14) but only at certain times of the year. The common observation by game guards was that elephants mainly eat mopane trees around October/November, when the leaves are fresh, potentially because there are fewer tannins in the leaves at that time, and also there is more sugar in the bark (Haynes, 2012). This observation by the game guards agrees with the findings of a study on the seasonal diet of elephants, which concluded that elephants eat a higher proportion of mopane in the dry season (Kos et al., 2012). One potential bias related to this specific species, is that mopane trees are abundant in the valleys, which tend to be where the villages are located, and therefore local people are more likely to observe mopane trees that have been browsed by elephants than other species.

Interview results were supplemented during this study with field observations, and this provided confidence in their knowledge. As discussed, trees that, according to game guards, are preferred by elephants, were observed in mountains to have been browsed (e.g. *Sterculia Africana* and *Commiphora* species). Another point providing confidence in the knowledge of the game guards related to their ability to identify tree species, including distinguishing between the similar species of *Commiphora mollis* and *Commiphora multijuga*. 14 of 34 game guards (41%) listed *Commiphora multijuga* in the Top 5 trees most preferred by elephants (Fig. 8). All 14 said that this species only occurs in mountains (Table 1). Of those 14 game guards, 12 are stationed in the more mountainous conservancies of Ozondundu and the northern part of

**Fig. 9.** *Sterculia Africana*, partly eaten by elephants, in the mountains above Omutirapo, Omatendeka Conservancy, February 2023.

**Fig. 10.** *Commiphora glaucescens*, partly eaten by elephants, in an area of rolling hills near Epako, Orupupa Conservancy, January 2023.

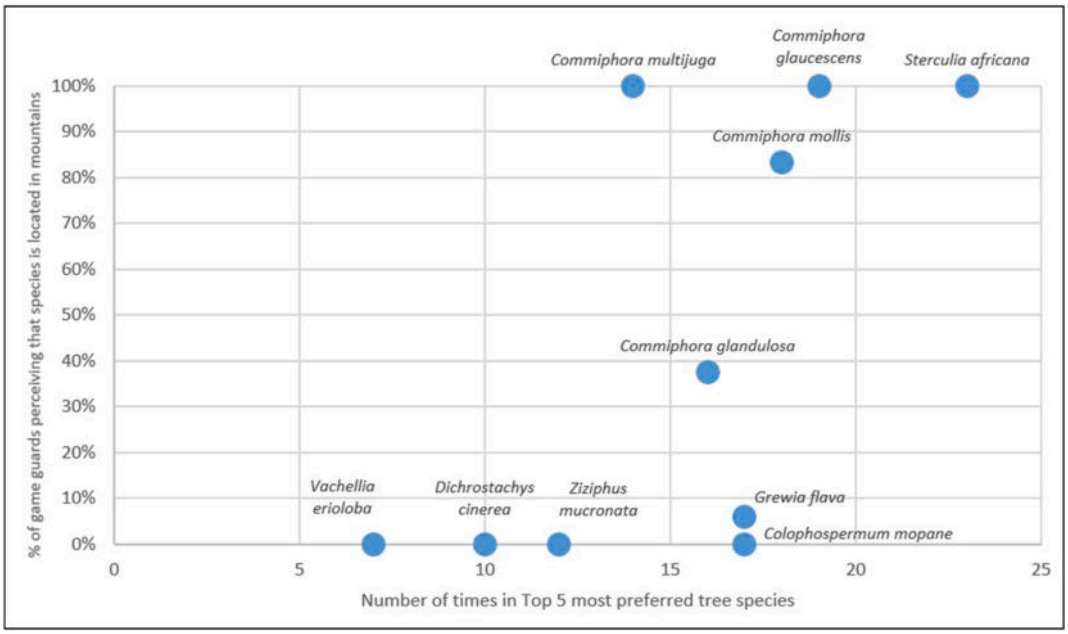


**Fig. 11.** Perception of game guards on whether tree species most preferred by elephants are located in mountains.

**Fig. 12.** *Commiphora mollis* (circled), partly eaten by elephants, in the mountains above Ondiwet, Omatendeka Conservancy, January 2023.

Omatendeka (Fig. 1). During field patrols, we observed this species to be abundant on the steeper slopes in those areas, but not in the eastern part of the Northern Highlands. This is confirmed by the distribution map developed under the Tree Atlas Project (NBRI, 2005). We observed the other *Commiphora* species across mountainous parts of the study area. The fact that 12 of 14 game guards that included *Commiphora multijuga* in the Top 5 most preferred by elephants are located in villages in the area where this species mainly grows demonstrates confidence in the ability of game guards to accurately identify species, particularly given that *Commiphora multijuga* is not easy to identify. Our study indicates that the game guards do have useful local ecological knowledge, although it should be noted that this applies to their local area (e.g. their village and surrounding villages) and they have less knowledge on the wider area.

**Fig. 13.** The Etosha landscape is mostly very flat with a small number of Dolomite outcrops (December 2020).

**Fig. 14.** *Colophospermum mopane*, near Okomutati, Ehi-Rovipuka Conservancy, April 2021. Some game guards suggest that elephants push over mopane trees to reach growing leaves at the top that might contain fewer tannins.

## 4. Conclusions

In the semi-desert landscape of the Northern Highlands, local knowledge of the vegetation species most preferred and least preferred by elephants proved useful in identifying movement patterns and factors affecting movements of elephants. This is an important component of research to inform the planning of conservation measures to protect elephants, including activities to support communities in reducing human-elephant conflict. Such measures are particularly important given the future climate change risks and potential impacts of severe droughts on the fragile habitats, wildlife and communities in the arid Highlands.

Some results from the consultation with community game guards are not surprising, such as their observation that elephants move after rains to find fresh vegetation, and that they eat most types of vegetation in the dry season when food sources are scarce. For example, there has been much previous research in different countries on these aspects of elephant movements and behaviour (Viljoen, 1989; Loarie et al., 2009; Young et al., 2009; Owen-Smith and Chafota, 2012; Garstang et al., 2014; Purdon et al., 2018; Tsalyuk et al., 2019; Birkett et al., 2012). The responses from the game guards provide confidence in their local ecological knowledge, which, for these general points, supports the conclusions from wider research.

There are common observations of game guards (Fig. 8) that there are specific species of tree in the Northern Highlands that elephants strongly prefer for browse. These are the African star chestnut (*Sterculia africana*) and *Commiphora* species, such as *Commiphora glaucescens* and *Commiphora multijuga*. These species grow on the rocky, steep slopes near the top of the mountains in the Northern Highlands. Observations in the field confirmed that elephants are walking up the mountains to select these species. The indications from the game guards are that elephants spend more time in the mountains in rainy season, partly because these food sources are in leaf and partly because there is often standing water away from the villages, so elephants do not need to visit community water points in the valleys as frequently.

Mopane (*Colophospermum mopane*) is the dominant tree species in the Northern Highlands, mainly growing in the valleys and on some lower slopes. The results confirm that this species might be an important source of vegetation for elephants towards the end of the dry season, when the leaves of mopane trees flush early and potentially contain fewer tannins, and when the bark contains more sugar.

The results also indicate that some species are clearly much less preferred despite being an important species for other browsers (e.g. smelly shepherd's bush (*Boscia foetida*), shepherd's tree (*Boscia albitrunca*), Herero sesame bush (*Sesamothamnus guerichii*) and leadwood (*Combretum imberbe*)). These species tend to grow in the valleys or on lower slopes.

The preferred trees, in particular *Sterculia africana* and the main *Commiphora* species, were observed to have a lower abundance than some species in the Highlands, such as the *Colophospermum mopane* and *Terminalia prunioides*. Despite the visible damage to trees in the study area, it can be assumed with confidence that at this time there is low risk from this population of elephants related to the carrying capacity in the Northern Highlands, because of the relatively low density of elephants. Further research is needed, however, to determine the browse capacity for elephants in northwest Namibia. In an early study on the influence of desert-dwelling elephants on vegetation in the northern Namib desert, to the west of the Northern Highlands, Viljoen and Bothma (1990) concluded that the desert-adapted elephant population in that area, which has much less vegetation coverage than the Northern Highlands, is well below the carrying capacity.

Increased commitment of local communities to wildlife protection, because of the community conservancies, and investments in community water points, mean that the level of wildlife protection and water availability in the Northern Highlands are nearly equivalent to inside Etosha National Park. The results of this study, from local ecological knowledge and field observations, provide confidence that a major factor in the increase in elephant population in the Northern Highlands, including movement from Etosha, is the preferred vegetation available on the mountain slopes of the Highlands compared to Etosha. Determining the relative abundance of the short-listed 20 species is necessary to comprehensively conclude that certain species are preferred, although the local-knowledge and observations provide valuable field indication of selection.

Local feedback indicates that, in the past elephants moved from Etosha to the Northern Highlands in the rainy season, but returned in the dry season. With improved water availability in the arid landscape, feedback from game guards is that some elephants are now staying in the Highlands where they were historically transient. This research on factors affecting elephant movements would benefit from more study on comparison with abundance of these vegetation species in Etosha National Park. A wider comparative study between the observed feeding preferences of this population with the desert elephant and Etosha populations will be of value to determine whether browse selection is unique to the Highlands population. Observed feeding preference can be supplemented with a dung analysis to determine feeding preference more quantitatively. Further studies would be enhanced by support to community game guards, including provision of equipment (e.g. binoculars, spotlights, reference books, etc) so that the studies can benefit from their involvement and local ecological knowledge.

Climate change events will potentially increase the competition between humans and elephants for natural resources in Namibia and other areas of elephant range in Africa. This risk further raises the need for research on elephant movements. Our study involved interviews with experienced community game guards, and we checked their knowledge through on the ground observations during foot patrols. Our confidence in the potential benefits of the knowledge of the game guards in the Northern Highlands is consistent with the conclusions from the study on elephants in northwest Botswana, which was also positive on the use of local experts to understand landscape use by elephants (Buchholtz et al., 2020). Future research elsewhere in Africa would benefit from including the use of local ecological knowledge in studies of elephant movements, particularly in areas of challenging terrain.

## CRediT authorship contribution statement

**Michael Wenborn:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vincent Nijman:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Ash Parton:** Writing – review & editing, Supervision, Conceptualization. **Magdalena S. Svensson:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Aho N. Nashongo:** Writing – review & editing, Investigation, Data curation. **Morgan Hauptfleisch:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

## 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.

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## Data availability

Data will be made available on request.

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