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Brief Report

Presence and Absence of Beehives as a Management Tool for Reducing Elephant-Induced Tree Mortality

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Abstract: Beehives have previously been used to protect large trees from elephant impact in sub-arid savannas, thus improving the persistence of large trees as habitats for other species. This brief report aimed to investigate the effectiveness of the presence and absence of beehives as a management tool for reducing elephant-induced tree mortality. The study was conducted in three phases: Phase 1 (2015–2020) involved actively maintaining beehives on marula trees (*Sclerocarya birrea* subsp. *caffra*), Phase 2 (2020–2022) the systematic reduction in the number of active beehives, and Phase 3 (2022–2024) the removal of all beehives. The persistence rates of the trees with beehives were compared to those without beehives. We found that beehives significantly improved the persistence of the trees in the presence of elephants. During Phase 1, only 10% of the trees with beehives died compared to 34% of the trees with no beehives. In Phase 2, with a reduced number of active beehives, the mortality rates increased slightly for both trees with beehives and those without. However, in Phase 3, after the removal of all the beehives, the mortality rates significantly increased for all the trees monitored as part of the study. We also found that the mortality rate of the original trees with no beehives increased when beehives were removed from the study site, whilst the mortality rate of the original beehive trees without beehives in Phase 3 (8.7%) surpassed that of the 8.1% prior to the hanging of beehives. These findings highlight the effectiveness of beehives as a tree protection method against elephant impact and how beehives can improve the persistence of tree populations co-occurring with elephants.

Keywords: beehives; elephant management; elephant impact; tree mortality rates; tree protection methods

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1. Introduction

African honeybees (*Apis mellifera scutellata*) housed in beehives have been used as a human–elephant conflict mitigation method across Africa where humans and African elephants (*Loxodonta africana*) compete over shared resources [1–3]. It is hypothesized that elephants are vulnerable to being stung on the sensitive regions of their ears, eyes, and trunks by notoriously aggressive African honeybees [4,5]. Besides being used to repel elephants from resources, African honeybees have the added benefit of providing honey as a means of economic income [1], which is important considering that building and maintaining beehive fences can be an expensive endeavor [6].

In South Africa, researchers have experimented with the use of African honeybees to protect marula trees (*Sclerocarya birrea* subsp. *caffra*) from elephant impact [7,8]. This has been carried out due to concerns about elephant impact on large standing tree (≥5 m [9]) populations in fenced-off protected areas, particularly where water is readily available to elephants and where elephant populations are expanding [10–12]. Marula trees, for example, are highly sought after by elephants due to their high nutrient content in the leaves, bark, and fruit [9,13], whilst providing an important food source and habitat to a large variety of fauna [14]. The loss of large trees may have negative confounding effects on the tree-reliant species of tree-nesting birds [15]. Beehives containing African honeybees were thus hung from the branches of adult marula trees (hanging 2 m above the ground) as a means of deterring elephants from pushing over these trees [7], with each tree containing a beehive paired with a tree without a beehive (treatment/control design). The initial results over nine months (the year 2015) suggested that the marula trees containing beehives had a significantly reduced probability of receiving elephant impact in comparison to the marula trees without beehives [7], reducing marula tree mortality from 8.1% per annum before the addition of beehives (2013–2015) [16] to 2% per annum after the addition of beehives (2015–2020) [8].

Owing to logistic constraints with study site accessibility and the need for the active beehives to be hung at a new location, *Elephants Alive*, the South African not-for-profit company responsible for this research, slowly reduced the number of beehives within the study site after 2020, until all the beehives were removed after seven years in 2022. Following the removal of the beehives, we had the opportunity to hypothesize that the marula trees that had once contained beehives would become more vulnerable to elephant impact, and the persistence rates of the former marula trees containing beehives would rapidly resemble those of the marula trees which never received a beehive, as well as the mortality rates of the marula trees prior to the project commencement. This would further substantiate the positive impact that the beehives had on protecting the trees from elephant impact. Therefore, two years after the removal of beehives, our objectives were (i) to assess the persistence rates of the former trees that had contained beehives and those that had not to investigate how the removal of beehives influenced these persistence rates, and (ii) to assess whether the trees that had never had beehives were extirpated at a higher rate when the density of active beehives decreased across the study period.

2. Materials and Methods

2.1. Study Area and Field Assessments

This study took place in the Jejane Private Nature Reserve (JPNR), a protected area within the Associated Private Nature Reserves (APNR) of the Greater Kruger National Park, South Africa (Figure 1a). A detailed description of the study site and design has been previously published [7,8]. Briefly, however, the APNR has a substantially higher density of waterholes (1 per 2 km^2) in comparison to the neighboring Kruger National Park (1 per 15 km^2) [17]. JPNR dropped its fences with the APNR in 2013, leading to an influx of elephants into the protected area from the APNR and consequently a rapid accumulation of marula tree mortality [16]. The study site containing the beehives fell within 2 km from a pumped artificial waterhole, and as no JPNR waterholes were closed for the duration of the study, JPNR served as an ideal study site for *Elephants Alive* to test the efficacy of beehives as a tree protection method in an area with high marula tree mortality [7,16]. During this study, the APNR elephant population ranged between 1875 (2017 census count) and 3599 elephants (2020 census count) (mean $\pm$ s.d.: 2917 $\pm$ 561).

We used a before–after control–impact approach for our study [18]. A total of 50 marula trees ($\geq$5 m in height) had one active beehive hung from their branches in 2015 (henceforth referred to as beehive trees in short), and Phase 1 of the project was initiated and ran until 2020. Each marula tree with a beehive was paired with the nearest marula tree ($\geq$5 m in height) that had no beehive added to its branches (non-beehive tree in short). During this phase, beehives were actively checked and maintained by the researchers, with supplementary feed (in the form of artificial nectar and pollen) provided to the honeybees weekly during the dry months when floral resources in the surrounding areas were low [7,19]. During these five years, the study's aim was to maintain the number of active beehives at the highest possible level, which enabled the study site to have an average active beehive occupancy of 26.3% (±s.d.: 22.1 for the duration of the five-year study period of Phase 1 (Figure 1b).

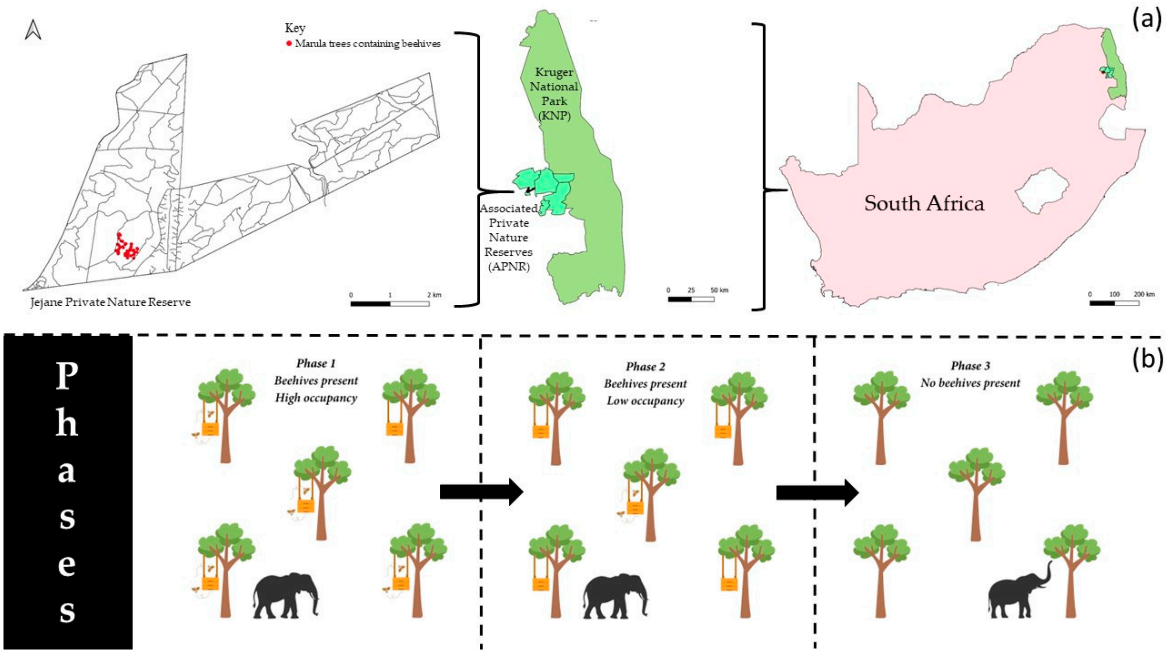

Figure 1. (**a**) Location of the Jejane Private Nature Reserve (JPNR) within the Associated Private Nature Reserves (APNR) of South Africa, and (**b**) a visual illustration of Phases 1–3, indicating the varying levels of beehive occupancy per phase.

During Phase 2 (2020–2022), only a small portion (mean ± s.d.: 5.1% ± 1%) of the active beehives from Phase 1 were left in the study site, strategically placed along the identified elephant pathways crossing through the site. The remaining beehive trees were left with inactive beehives hanging from their branches (Figure 1b). The honeybees were still actively fed every week during the dry months. Phase 2 aimed to identify whether a small number of active beehives at strategically placed locations could instill a conditioned fear response from the elephants towards the beehives, with the few active beehives potentially conditioning the elephants to avoid all the trees with beehives [20].

Phase 3 (2022–2024) started with the removal of all the active and inactive beehives from the study site, and thus the surviving marula trees that had contained both active and inactive beehives now resembled the non-beehive trees in appearance (Figure 1b).

Field surveys, where the status of each beehive and non-beehive tree (alive or dead) was assessed, were carried out every year in Phase 1, after which the surveys were repeated at the end of Phases 2 and 3, respectively.

2.2. Statistical Analyses

Statistical analyses were carried out using R version 4.3.0 and were considered significant at $p < 0.05$. To test for significant differences between the persistence proportions of marula trees that were originally selected for beehives versus marula trees without beehives from 2015 to 2024, we performed a Kaplan–Meier survival analysis (*survival* package [21]) with the Holm–Sidak post hoc test [22]. The death of a tree was considered a truncated event (termed 1) whilst the persistence of a tree was considered censored (termed 0).

Annual mortality rates were calculated as follows: $\text{mortality} = 1 - (1 - \text{mortality}_i)^{1/\text{years}}$, with mortality_i referring to the overall percentage mortality occurring during the specified study period, and years referring to the number of years that pertained to the study period of interest [23].

A chi-squared test was used to test for significant differences between the number of surviving and dead beehive trees during Phases 2 (the physical presence of beehives in the study site) and 3 (no physical presence of beehives in the study site).

3. Results

We found that the presence of beehives significantly improved the persistence of large trees co-occurring with elephants (Log-rank test = 10.03, d.f. = 1, $p < 0.01$, Figure 2). After Phase 1, only 10% of the beehive trees had died in comparison to 34% of the non-beehive trees (Table 1). After Phase 2, the number of dead beehive trees had increased to 16%, substantially lower in comparison to the 46% dead non-beehive trees (Table 1). This represented a near-double percentage increase in mortality rates for the unprotected trees (6% versus 12%) or so-called beehive versus non-beehive trees between Phases 1 and 2 (Figure 2, Table 1). However, in Phase 3, following the removal of all the beehives from the site, the annual mortality rates for both the beehive and non-beehive trees increased considerably (Table 1), with 46% of the original beehive trees dead versus 70% of the non-beehive trees (Table 1). The overall annual mortality rate of the trees containing beehives thus increased significantly between Phases 2 and 3 ($X^2_{(1,87)} = 11.2$, $p < 0.001$), from 3.1% to 6% per annum, respectively (Table 1). Notably, almost double the number of the original beehive trees died in the two years of Phase 3 in comparison to the accumulated seven-year period of Phases 1 and 2. For the non-beehive trees, the mortality percentage saw a 12% increase from Phase 1 to 2 which then doubled again when moving from Phase 2 to 3 (24%), thereby showing that as the beehive presence at the site decreased over time, the mortality rate of the unprotected trees exponentially increased over time.

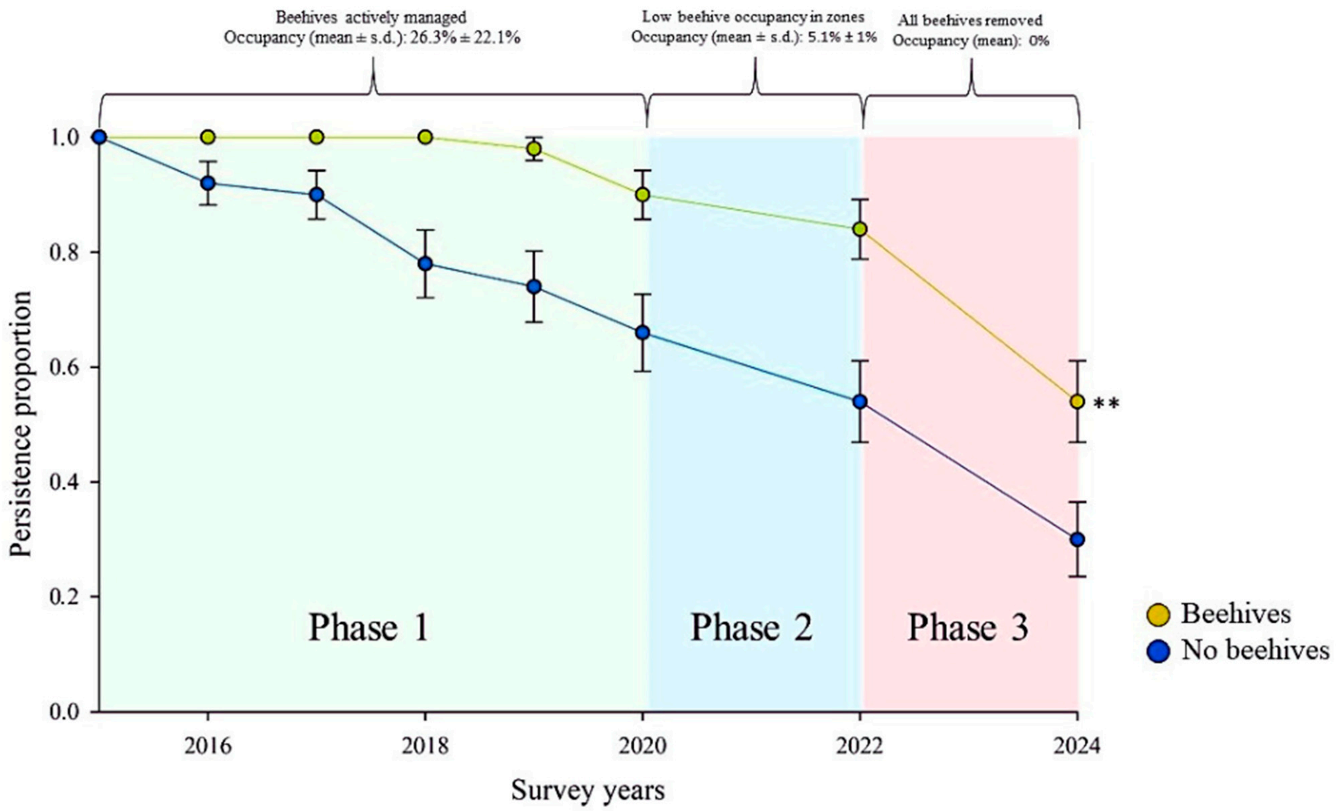

Figure 2. Persistence proportions of the marula trees with beehives present and absent across Phases 1–3 of the study within the Jejane Private Nature Reserve (JPNR) within the Associated Private Nature Reserves (APNR) of South Africa. ** $p < 0.01$.

Table 1. Mortality of the marula trees with beehives present and absent during Phases 1–3 of the study within the Jejane Private Nature Reserve (JPNR) within the Associated Private Nature Reserves (APNR) of South Africa.

	Phase 1 **2015–2020**		**Phase 2** **2020–2022**		**Phase 3** **2022–2024**	
Percentage of beehives active per month (mean ± s.d.)	26.3% ± 22.1%		5.1% ± 1%		0%	
Tree type	Beehive	Non-beehive	Beehive	No beehive	Beehive	No beehive
Accumulative percentage of trees dead since 2015	10%	34%	16%	46%	46%	70%
Overall annual mortality rate since 2015 (% per annum)	2.8%	7.6%	3.1%	7.4%	6%	8.7%

4. Discussion

This brief report provides the first known assessment of the mortality rates of trees after the removal of beehives as a tree protection method against elephant impact. Whilst the success rate of beehives at improving marula trees' persistence versus non-beehive trees has been previously published [7,8], our study highlights the success rate of this method by focusing on the fate of the trees post-beehive removal. Using beehives to protect trees from elephant impact is a relatively expensive method in comparison to other methods such as wire-netting [8]; however, beehives still prove to be a highly effective method for individual tree protection, as illustrated by our results in Phases 1 and 2, and further emphasized by the fate of the beehive trees in Phase 3.

The results from Phase 2, where only a small percentage of beehives were active, suggest that the high density of active beehives in Phase 1 may have conditioned the elephants to avoid the trees with beehives, regardless of whether the beehives were or were not active. This effect may have then been further strengthened by maintaining a small number of active beehives within the study site. This conditioned fear response has been previously studied on an array of species including rats (*Rattus norvegicus* [24]), rabbits (*Oryctolagus cuniculus* [25]), and chacma baboons (*Papio ursinus* [26]). There is also some evidence from Kenya that elephants may show a conditioned fear response to empty beehives protecting crop fields following previous exposure to active beehives [27]. Whilst we hypothesize that elephants will eventually decipher which beehives are active and which are not, there may be a window period, as suggested by Phase 2, where the trees protected by inactive beehives can still be protected against elephant impact if there is some form of a behavioral reinforcement (in our case, a small number of active beehives) to prolong the conditioned fear response.

The scale of the implementation of the beehive tree protection method will always be limited due to the cost and maintenance of the beehives [8,19], as well as concerns over pollinator competition between African honeybees and other native pollinators [28]. The aggressive nature of African honeybees also means that there is a safety risk to the protected area staff who may be in charge of monitoring the beehives, or stakeholders (e.g., tourists) driving near beehives. However, our results suggest that beehives can play an important role in protecting individual trees from elephant impact (Phases 1–2) and areas such as the study site due to the accelerated loss of unprotected trees during Phases 2–3, with this result being further supported by the high mortality rates of the trees following the removal of the beehives (Phase 3). Whilst the annual mortality rate in Phase 3 (8.7%) surpassed the reported annual mortality rate of 8.1% prior to the addition of beehives [16], it is still a large increase from 2% when the beehives were present [8]. The presence of the beehives on the trees may have had a small spatial effect on protecting the surrounding trees from elephant impact by potentially decreasing the time that the elephants spent in the study site (suggested by the increased decline of the original unprotected trees between

Phases 2–3). However, this hypothesis requires further testing using the collared elephant data from *Elephants Alive*.

Beehives, as a tree protection method, are just one "tool" in a "toolkit" of the elephant management methods available to mitigate elephant impact on large trees [12,29]. Details on management methods operating at larger scales and influencing elephant densities, both spatially and temporally, have been discussed at length elsewhere [12]. Tree protection methods, however, are still a viable option for improving the persistence of adult trees as habitats and as potential seed banks for future tree populations in protected areas containing elephants [30]. Stakeholders can also adopt the use of beehives, thus adopting a citizen management approach whereby interested stakeholders are trained in beekeeping practices, thus taking ownership of the project [31]. These methods may play an even greater role in the protected areas where water is readily available to elephants, as high densities of artificial waterholes lead to elephants remaining within relatively smaller spatial areas for greater lengths of time, increasing the probability of elephant-induced tree mortality within these areas [32]. Importantly though, the loss of large trees in protected areas containing elephants is a complex matter, with tree-population persistence further being affected by drought [33], seed predation [34], seedling herbivory [35], fire [36], and a combination of these interacting factors with elephant impact [12,37]. Beehives, however, when applied correctly to a tree, have the potential to prolong the tree's survival.

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Data Availability Statement: Data for this study can be requested from the NPO *Elephants Alive* through a written request to the authors.

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