frontiers | Frontiers in Conservation Science

TYPE Original Research
PUBLISHED 16 April 2025
DOI 10.3389/fcosc.2025.1553217

OPEN ACCESS

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RECEIVED 30 December 2024
ACCEPTED 26 March 2025
PUBLISHED 16 April 2025

CITATION
Rabemananjara HB, Bodenburg C, Schüßler D, Asadi Y, Ratsirarson J, Razafindramanana J, Rasamimanana H, Richter T and Meisert A (2025) Local ecological knowledge about pest control offers novel perspectives for Aye-aye conservation.
Front. Conserv. Sci. 6:1553217.
doi: 10.3389/fcosc.2025.1553217

Local ecological knowledge about pest control offers novel perspectives for Aye-aye conservation

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Introduction: Local ecological knowledge (LEK) offers valuable insights into human-wildlife relationships and bears the potential to improve the conservation of controversial species. The Endangered and elusive Aye-aye (*Daubentonia madagascariensis*) is commonly associated with superstition and negative perceptions that lead to targeted killings, but has recently been related to agricultural benefits. This study explores how knowledge about ecological interactions in clove agroforestry underlies this benefit perception.

Methods: Through surveys (n = 392) and expert interviews (n = 6) across 21 village communities, we assessed Aye-aye-related LEK among clove farmers in northeastern Madagascar. Survey analysis employed a Random Forest model and expert interviews were analyzed using qualitative content analysis.

Results: Clove farming experts emphasized the beneficial effect that an Aye-aye has by suppressing invertebrate pest species on clove trees. About 44% of the survey participants related the Aye-aye to pest control and knowledge of its insectivory was identified as a critical factor influencing this benefit knowledge. Diverse levels of LEK about the Aye-aye were recorded and were influenced by gender, socio-economic activities, and geographic location.

Discussion: The results underscore the importance of ecological knowledge as a condition for benefit perception and demonstrate how assessing LEK can provide insights into the perception of cryptic wildlife species. This study illustrates the necessity for targeted conservation actions, sensitive to socio-ecological contexts. Conservation practitioners should employ benefit-based narratives if available and consider local knowledge transmission channels to address negative perceptions of wildlife."

KEYWORDS

benefit perception, social-ecological systems, clove agroforestry, human-wildlife interactions, Madagascar, lemur conservation, *Daubentonia madagascariensis*

1 Introduction

The importance of local ecological knowledge (LEK) to inform species conservation in biodiversity hotspots has been widely acknowledged (Anadón et al., 2009; Sheppard et al., 2024; Camino et al., 2020; Ravaoarinorotsihoarana et al., 2023). LEK encompasses knowledge and practices regarding species and ecological interactions that local land users have developed through and for ecosystem management (Berkes et al., 2000). An individual's LEK about a species is deeply connected to environmental perceptions, values and beliefs, reflecting the socio-ecological system in which the respective human-wildlife relationship is embedded (Berrouët et al., 2018; Joa et al., 2018). Human relationships with controversial wildlife species like apex predators, bats, snakes, or elusive mammals usually appear complex and cryptic, which impedes their conservation (Nonga and Haruna, 2015; Pooley et al., 2017; Tanalgo et al., 2016; Gunn et al., 2024). Here, assessing LEK can particularly provide insight into the perceptions and values that are associated with the respective species. For example, Catapani et al. (2023) used LEK to successfully improve the understanding of superstitions toward the giant anteater in Brazil, demonstrating the potential of LEK for developing locally adapted transformation measures.

One of these controversial animal species is the Endangered and elusive Aye-aye (*Daubentonia madagascariensis*) in Madagascar, for which, the dimensions of LEK have not yet been comprehensively investigated. The Aye-aye is the largest nocturnal primate, lives solitary, occurs in low population densities and usually remains high up in the canopy (Randimbiharinirina et al., 2018). The rodent-like incisors, protruding ears, and elongated middle fingers are adaptations to its unique foraging strategy, which enable the acoustic localization and manual extraction of larvae from wooden tissue (Sterling and Richard, 1995). However, its unusual appearance and the rarity of encounters with humans have fostered cultural narratives that associate the Aye-aye with imminent bad luck and misfortune (Simons and Meyers, 2001; Randimbiharinirina et al., 2021). Local strategies to avert expected misfortune are targeted killings of sighted animals and even the abandonment of villages after an Aye-aye sighting has been reported (Goodman, 2015; Glaw et al., 2008). This negative perception has been described to be a major threat to the species and is continuously being reproduced by both scholars and journalists. Nevertheless, there is still no differentiated understanding of the formation and dissemination of these narratives. Therefore, conservation actions for the Aye-aye continue to lack a profound understanding necessary to address these negative perceptions toward the Aye-aye.

Quite recently, Randimbiharinirina et al. (2021) were the first to notice that local perspectives on the Aye-aye are more complex than previously assumed. They reported that some clove farmers in northeastern Madagascar perceive the Aye-aye as beneficial as it controls invertebrate pests such as the clove-leaf-miner (*Chrysotypus mabilianum*; Dubois and Ranaivosoa, 1966) on clove trees (*Syzygium aromaticum*), a major cash crop in the region. This benefit knowledge is promising as the perception of nature's contributions to people proved to be a critical factor for local support and success of conservation approaches, especially in subsistence communities (Díaz et al., 2015; Harvey et al., 2018). For example, Bhattacharjee et al. (2022) reported that farmers in Nepal who recognize scavengers' ecological roles, such as carcass consumption and biological control, are more likely to view these species as beneficial and support their conservation. Correspondingly, negative perceptions were linked to low species identification - and ecological knowledge levels regarding the Aye-aye (Randimbiharinirina et al., 2021) and other species like the giant anteater (*Myrmecophaga tridactyla*; Catapani et al., 2023).

Taking into account the apparent complexity of perceptions of the Aye-aye (Randimbiharinirina et al., 2021), assessing LEK can reveal what humans perceive as meaningful regarding this particular wildlife species (Ausubel et al., 1978). Thus, it may provide insight into factors that might motivate people to support Aye-aye-conservation (Nkengbeza et al., 2024). Furthermore, revealing the sources of knowledge can help to identify key mechanisms and target groups for specific conservation measures. Building on this potential for conservation research and practice, this study aims to (1) assess the knowledge that local land users hold about the Aye-aye, (2) investigate how it is perceived to generate benefits for local people by identifying interactions that are seen as meaningful to the community, and (3) outline which general knowledge, socio-demographic and geographic variables are related to holding benefit knowledge about the Aye-aye.

2 Methods

2.1 Study area

The survey was conducted around Makira Natural Park in northeastern Madagascar, which accommodates the country's largest remaining low-altitude rainforest area with exceptional levels of biodiversity (Brown et al., 2014; Brown and Yoder, 2015; Holmes, 2007). The protected area was established in 2006 to control ongoing deforestation. It is managed by the conservation NGO Wildlife Conservation Society (WCS) through a zonation scheme of strict protection and restricted use areas (Figure 1). The latter provide a livelihood for approximately 50,000 people living in the parks' surroundings (Brimont et al., 2015). Village structures are characterized by mostly small and few medium-sized, remote settlements and little infrastructure (Schüßler et al., 2020). Subsistence agriculture barely covers nutritional demands and local livelihoods are under tension (Golden et al., 2019). Subsistence farming is complemented by the cultivation of cash crops like cloves (Danthu et al., 2014) and vanilla (*Vanilla planifolia*) thereby providing a significant source of income for most households. Farming practices are mostly restricted to non-technical manual labor and are vulnerable to pests and external environmental impacts (Mariel et al., 2021). With little health infrastructure available, medical aid is mostly provided through the use of ethnobotany (Golden et al., 2012). Resource use and human-wildlife relations are strongly governed by informal rules (fadys) that are rooted in ancestral beliefs (Jones et al., 2008; Golden, 2009; Von Heland and Folke, 2014). These regard species-, places- and, food-related practices and show high local

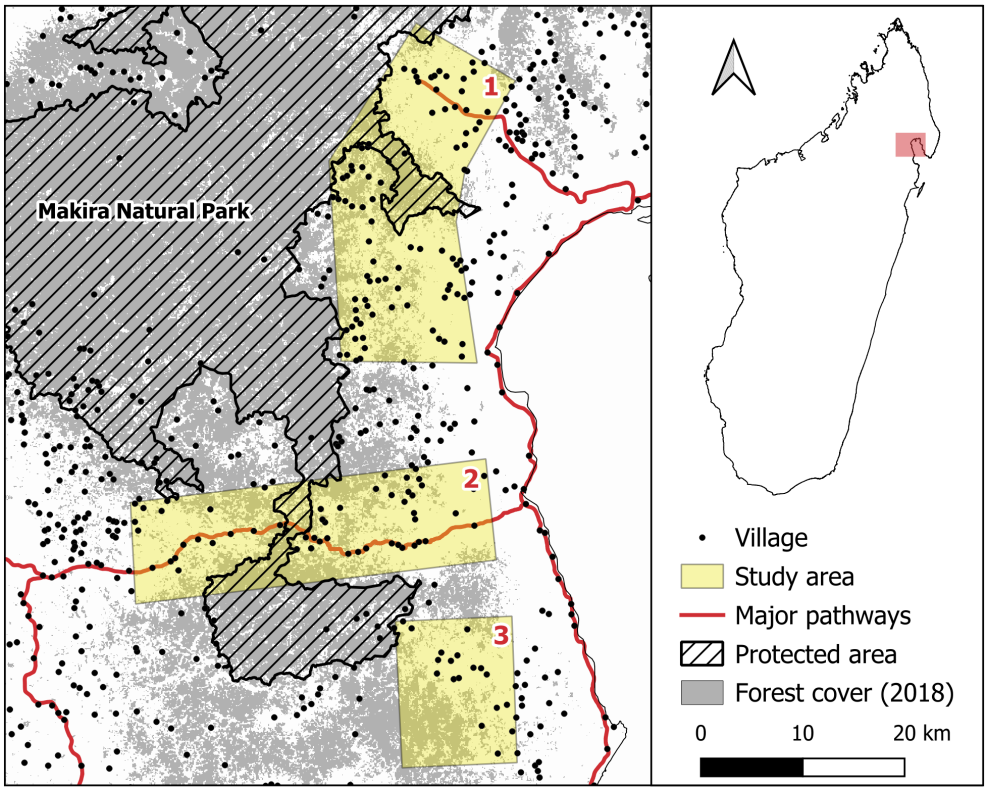

FIGURE 1
Study region around Makira Natural Park in northeastern Madagascar with the designation of surveyed subsections. Forest cover and the location of villages from Schüßler et al. (2020).

variation even across the smallest geographical scales. Formal education in terms of primary schools exists in medium-sized villages and secondary education is only available in the cities inland and along the coast. Thus, formal knowledge levels are rather low (4.6 years of mean duration of schooling; UNDP 2024) and informal knowledge transmission channels such as social learning are of high significance.

The study area is subdivided into three different subsections (Figure 1). These differ in some key aspects such as the location along a major pathway (subsection 2), which may promote the transmission of information, being directly impacted by protected area management and conservation activities, and (subsections 1 & 2) being distant from the protected area and disconnected from major transport routes (subsection 3).

2.2 Data collection

To capture knowledge resources as well as socio-demographic data, semi-structured surveys and open interviews were conducted across the three subsections (Figure 1). The study design followed the structure of an educational research study that assesses local perceptions of the Aye-aye before and after an educational intervention. The current investigation constitutes the pre-survey. It complies with the ethical standards of the Helsinki Declaration, as well as standards for research in Madagascar (Wilmé et al., 2016) and was approved by the ethics committee of the University of Hildesheim, Germany. The research was carried out with the consent of forest authorities, protected area management, and leaders of each respective community (Chef Fokontany & Chef Secteur).

In March-May 2022 and 2023, we conducted surveys and interviews (HBR, CB) together with a local guide in Betsimisaraka, the local Malagasy dialect. The communities were selected to represent the typical village size in the region, with additional considerations given to accessibility, the presence of clove farming and dependence on the forest as a primary source of livelihood. Respondent selection was based mostly based on availability, representing a convenience sampling approach (Etikan et al., 2016). Surveys lasted between 15 and 45 minutes and were based on the basic principles of confidentiality, non-disclosure, and voluntariness which were explained verbally to the respondents beforehand. Personal information of respondents such as names and interview location were recorded to allow the alignment of pre- and post-surveys in the evaluation study, as common re-identification methods such as reproducible personal codes were not reliable due to the high illiteracy rates. To ensure confidentiality, participants were free to withhold their personal information, which is securely stored and not disclosed. Clove farmers showing distinctive ecological knowledge were further asked to participate in an open expert interview (see below), in which answers were documented by written transcripts or audio recordings if consent

was given by the interviewee. The interview guideline consisted of five open questions which, in addition to these focal ecosystem interactions, covered general conditions of clove farming and its contributions to local livelihoods (S2).

To capture LEK within the Aye-aye-clove-farming-interface, the survey questionnaire and interview guidelines were designed to represent basic aspects of this concept. LEK potentially includes both knowledge about species and ecosystem interactions as well as the derivation of natural benefits such as food items, cash crops, or forest products (Joa et al., 2018; Díaz et al., 2015; Dee et al., 2019; Charnley et al., 2007). Species knowledge is assessed in the survey by identification items and the specific knowledge items on the Aye-aye. Knowledge about the interplay of clove trees, invertebrate pest species, and the Aye-aye was recorded by both, survey and interview. Further, socio-economic and geographic factors were assessed in the survey to detect potential patterns in LEK occurrence. All survey items were piloted to ensure coherent understanding, which resulted in specific adaptations of common question formats. As the comprehension of Likert-type scales was challenging for respondents during the pilot phase, binary survey items with simple, polarized answer options in accessible language (i.e., "Yes"or "No", and "Good" or "Bad"; S1) were created. Photos of local lemur species were shown to participants to assess their ability to identify an Aye-aye from a photo. Further, answer options for the recognition of feeding traces, and body-size estimation were visually illustrated (Table 1, Supplementary Table S1). Open questions were used to assess further aspects of ecological knowledge about the Aye-aye and answers were coded binary as correct or incorrect.

2.3 Data analysis

2.3.1 Expert interviews

The interview transcripts were analyzed using MAXQDA 24 Analytics Pro. A structured coding system was developed to categorize the data, providing a framework to identify perceptions of the Aye-aye in relation to clove farming and threats to clove farming and highlight the meaningful interactions between them. The coding process was inductive, with codes derived directly from expert survey responses. Transcripts were translated and coded in English. HBR is a native Malagasy speaker and ensured linguistic accuracy. To ensure inter-coder-reliability, two researchers (TR and HBR) independently applied the coding system to a random subset of the data. The inter-coder agreement, measured by Cohen's Kappa, was 0.83. Any discrepancies between coders were resolved through discussion, leading to an updated version of the coding system. The final coding system included four major categories, 14 codes, and 18 sub-codes (S3). The categories were: (1) knowledge of ecological elements, (2) knowledge of interactions, (3) human evaluation, and (4) sources of knowledge. To analyze knowledge and perceptions of the Aye-aye's benefits related to clove farming, the Code Relations Browser was used to examine the relationship between (two) elements. The "close proximity" option was set to a maximum distance of one paragraph, and results were visualized using MAXMaps. For more complex interrelationships between codes, the Complex Coding Query was applied, specifically the "if inside" retrieval function, to find segments where one code was nested inside another. Interactions were assigned to the elements by assessing instances where their associated codes overlapped. Likewise, the subjective evaluation of an interaction was assessed by analyzing the overlap of respective codes.

2.3.2 Knowledge surveys

The quantitative data analysis was conducted using R (R Core Team, 2022), RStudio (RStudio Team, 2020), and Python (Python Software Foundation, 2023). To investigate which factors, characterize holders of clove benefit knowledge, we performed a model-building process with "Benefit knowledge" as the target variable which refers to people's knowledge of the benefit of the Aye-aye in clove farming(S1, Q24). Categorical variables were transformed into binary features, that described the different variants of the variable using one-hot encoding (Probst et al., 2019). Chi²-tests were employed to examine the relationships between them. As features showed strong levels of inter-dependence, multicollinearity among predictors was assessed using the Variance Inflation Factor (VIF) (Marquardt, 1970). Features showing a significant association with the target variable ($p < 0.05$) and an acceptable level of multicollinearity (VIF < 5) were used to train three common models: logistic regression, Random Forest, and

TABLE 1 Socioeconomic and geographic variables and percentage of respondents showing the respective expression.

Variable		%	Variable		%
Age group	<21	14.0	Gender	Male	65.8
	21-30	34.4		Female	34.2
	31-40	21.7	Encounter	Yes	19.1
	41-50	12.0		No	80.9
	51-60	12.0	Formal education	None	26.3
	>61	5.9		Primary	47.2
Ethno-botany	Yes	47.4		Secondary	20.7
	No	52.6		High school	5.8

XGBoost (Breiman, 2001; Hosmer et al., 2013; Chen and Guestrin, 2016). Model performance was evaluated using accuracy, recall, F1-score, and the Area Under the Receiver Operating Characteristic Curve (AUC; Supplementary Material S5). From the best-performing model, Permutation Feature Importance (PFI) values were calculated. PFI is a model-agnostic method that assesses the relative feature importance by measuring the reduction in model performance when the feature's values are randomly shuffled. A high PFI value means the feature has a strong influence on the model's performance. Features showing at least a minor positive effect on the target variable (PFI > 0.01) were considered for further interpretation.

3 Results

3.1 Study population

Semi-structured surveys were conducted with 392 adult village residents aged 15-97 years (M=35.0; SD=14.4). Males made up about two-thirds of the sample and the majority of respondents engaged in less than six years of formal education (M=3.9; SD=3.3; Table 1). A similar number of respondents participated in subsections 2 and 3 (six communities respectively). Subsection 1 included nine communities and accordingly, respondent numbers were slightly higher.

3.2 Quantitative interviews

The survey showed mixed levels of LEK about the Aye-aye across the respective identification and knowledge items. While most respondents (73.0%) knew the Aye-aye by its name, few (18.9%) could correctly identify it from a photo (Table 2). In contrast to that, almost three-quarters of all respondents were able to recall one of the two other lemur species surveyed (*Indri indri* & *Microcebus jonahi*). About 19.1% stated that they had already encountered an Aye-aye (dead or alive). The levels of the specific knowledge items on the Aye-aye were low for knowledge of signs (21.2%) and size (26.7%), moderate for knowledge of insectivory (37.8%), solitary lifestyle (43.4%), low abundance (52.3%), taxonomy (54.1%) and nocturnality (54.3%) and high for protection status (73.7%). The effect of the Aye-aye on clove farming was perceived as beneficial by 44.1% of respondents (Supplementary Material S4).

TABLE 2 General ecological knowledge items about the Aye-aye, indicator name and percentage of respondents showing (Yes) or not showing (No) the respective knowledge (n = 392).

Item name	Survey question	Yes %	No %
Benefit knowledge	Does the Aye-aye have an effect on clove farming?	44.1	55.9
Aye-aye name knowledge	Do you know the Aye-aye?	73.0	27.0
Aye-aye identification knowledge	Can you name these animal? (Photo of the Aye-aye)	18.9	81.1
Lemur identification knowledge	Can you name this animal? (Photos of Indri and Mouse lemur)	72.7	27.3
Insectivory knowledge	What does the Aye-aye feed on?	37.8	62.2
Signs knowledge	Which sign indicates the presence of an Aye-aye?	21.4	78.6
Size knowledge	Which other animal is similar to the Aye-aye in size and weight?	26.7	78.8
Lifestyle knowledge	Does the Aye-aye live solitary, in pairs or (family)groups?	43.4	56.6
Activity knowledge	At what time of the day is the Aye-aye most active?	54.3	45.7
Protection knowledge	Is the Aye-aye protected by law?	73.7	26.3
Abundance knowledge	Is the Aye-aye rare or abundant?	52.3	47.7
Taxonomy knowledge	Is the Aye-aye a lemur?	54.1	45.9

3.3 Expert interviews

Six expert interviews were conducted in five communities with clove farmers showing distinctive knowledge about the Aye-ayes' larvae picking and its implications for clove farming. The qualitative content analysis of the interview transcripts resulted in 218 encodings in the four general code categories "knowledge of ecosystem elements", "knowledge of interactions", "human evaluation" and "knowledge source" (Full code system S3). Central elements that were described in this context were "Cloves", including its trees and crops (47 encodings; Figure 2), larvae of the clove-leaf-miner locally known as "Andretra" (26 encodings), and the "Aye-aye" (28 encodings). Furthermore, the knowledge that was expressed about these elements covered "Conditions" and "Threats" to clove farming as well as temporal trends in the abundance of a respective code ("Evolution"). Non-technical, manual labor was described as the central input throughout the essential steps of nurturing, caring, and harvesting cloves. The experts demonstrated an in-depth understanding of how targeted cultivation practices in each of these steps can improve conditions, minimize threats, and thus maximize the output of the clove farming process (25 encodings). The importance of revenues from selling cloves for ensuring food security of families/communities and funding education for children (9 encodings) was emphasized.

The interaction "Pest" between Andretra and clove trees is notably strong, with 28 common occurrences. It was evaluated as negative by experts (Figure 2). Andretra was described as burrowing into the wood and feeding on the leaves, which negatively impacts tree survival and clove harvest. To prevent further crop losses and protect neighboring trees, farmers cut the affected branches. Despite the harm caused, farmers have not yet found a less destructive solution (Figure 2). The

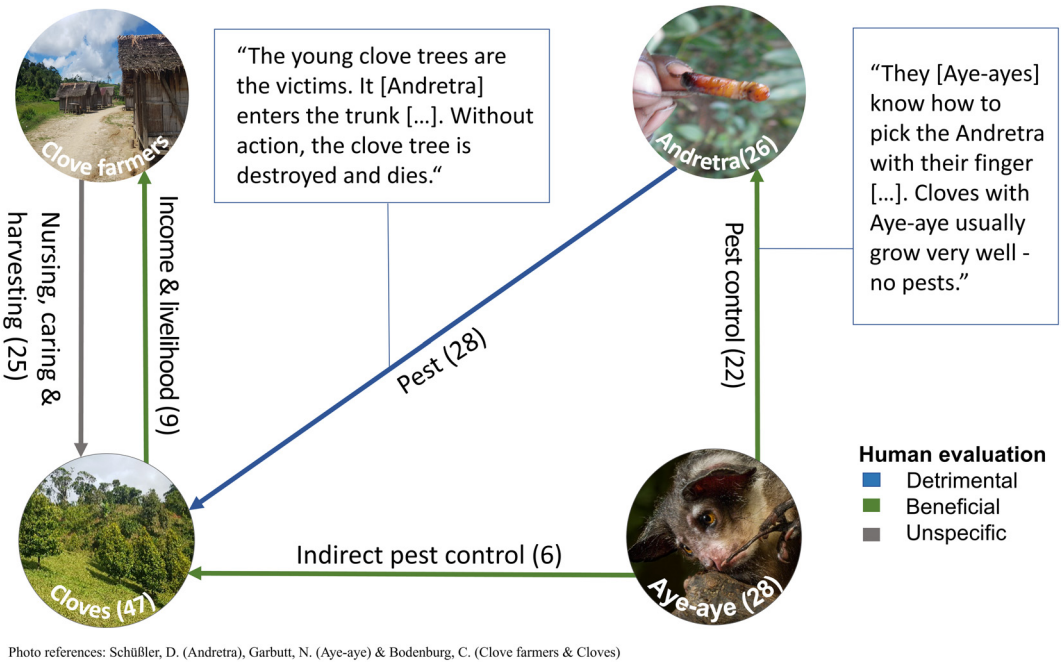

FIGURE 2
Perceived ecosystem elements and interaction within the Aye-aye-clove-agroforestry interface. The concept scheme was derived from code abundances for ecosystem elements and instances of overlap between interactions, elements, and evaluation with quotes from interview transcripts. The numbers in parenthesis represent the results of code abundance and overlap interactions between elements.

interaction "Pest control" involved the Aye-aye and Andretra (27 overlaps). The Aye-aye was described as feeding on the larvae by using its finger to extract Andretra from the tree branches. Thus, it prevents further crop damage, while rarely harming the tree in the process. The suppressing effect of the Aye-aye on Andretra is associated with improved clove survival (and harvest) and is evaluated positively (Figure 2). The sources of knowledge about the Aye-aye were only mentioned occasionally. They included stories passed down from ancestors, direct observations, and one respondent referred to a visual representation in a book.

3.4 Factors influencing benefit knowledge

After One-hot-encoding the categorical variables, chi²-tests were conducted with 34 binary features, of which 19 showed significant dependence on benefit knowledge. Three features were disregarded due to high multicollinearity ("clove farming", "ethnic group" and "village size"; S6). The Random Forest model outperformed other approaches (S5) by yielding a prediction accuracy of 78.0% and an AUC = 0.793. In this model, five features did not exceed the threshold of critical relative importance PFI > 0.010 (S6). The remaining 13 features with the highest importance for "benefit knowledge" in the RF-model, can be divided into nine knowledge features and four socioeconomic or geographic features.

All knowledge items were connected to benefit knowledge in the bivariate assessment but differed regarding relative feature importance (Figure 3). Knowledge of insectivory (PFI = 0.064) and "knowledge about the Aye-ayes' nocturnal lifestyle" (PFI = 0.043) were among the overall most important variables and showed moderate direct effects on benefit knowledge. Moreover, high relative feature importance was recorded for "knowledge of the legal protection status" (PFI = 0.033) and the visual identification items (Aye-aye: PFI = 0.024; indri, mouse lemur: PFI = 0.021; Figure 3). Weak connections to benefit knowledge were detected for knowledge of size (PFI = 0.015) and knowledge of feeding traces (PFI = 0.017). Randomizing the results for "knowing the Aye-ayes' name" improved model performance (PFI = -0,002).

Among the socioeconomic and geographic factors, gender showed high relative importance (PFI = 0.05) as male respondents were more likely to hold benefit knowledge. The collection of medical plants was the only livelihood activity that was listed as important (PFI = 0.019; Figure 3). Holders of benefit knowledge were present across all 21 communities. High feature importance (PFI = 0,037) and negative dependence were found between benefit knowledge and subsection 2 (along the main pathway). No significant effect was found for interregional migration, age (except age group 51-60: PFI = 0,017), formal education levels, and forest cover.

4 Discussion

4.1 A novel perspective on the human-Aye-aye relationship

By consulting local ecological knowledge (LEK) about the Aye-aye we were able to reveal a more pluralistic perspective on this

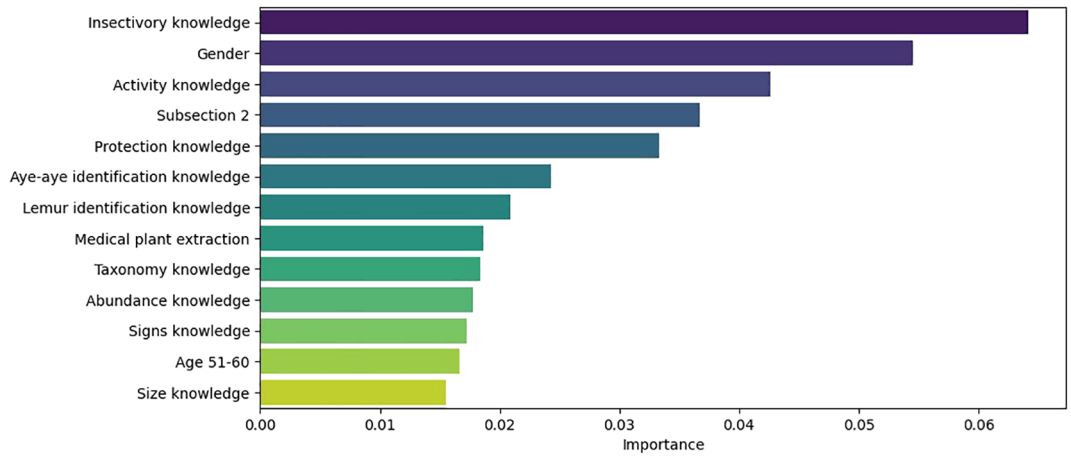

FIGURE 3
Features showing notable permutation feature importance scores (PFI>0,01) in a Random Forest model targeting benefit knowledge.

controversial lemur species beyond persistent established research narratives. Previous reports framed perceptions of the Aye-aye mainly within the narrative of superstition and resulting targeted killings (Simons and Meyers, 2001; Glaw et al., 2008; Goodman, 2015). Such reports are undoubtedly valuable and the persistence of this notion has been documented in the survey. However, in our survey about two out of five respondents also or exclusively associated the Aye-aye with benefits for clove cultivation. This demonstrates the capability of local ecological knowledge (LEK) to refine the understanding of complex human perceptions of wildlife species within social-ecological systems (Catapani et al., 2023). While the insectivorous diet of the Aye-aye is well documented in the scientific literature (Sefczek et al., 2019), the reports about natural pest control by the Aye-aye extend the knowledge of regulating ecosystem services provided by lemurs. Previously, mostly seed dispersal and pollination were reported (Meier and Albignac, 1991; Martinez, 2014). Apart from Randimbiharinirina et al. (2021), this contrasting notion has not been documented before and only reported in Makira Natural Park. This investigation is the first to provide a deeper understanding of benefit-based knowledge regarding the Aye-aye.

4.2 Benefits determine the relevance of knowledge

In the interviews, clove farmers evaluated information based on whether it was expected to influence their livelihood. ("I think that its [clove farming] impact on the community's livelihoods is good […] because […] it brings good money and income."). Specific LEK about farming processes, including species, ecological interactions, and environmental conditions, is essential for subsistence communities to derive natural benefits (Golden, 2009; Zaehringer et al., 2017; Schüßler et al., 2024). The perception of benefits provides meaning to knowledge and may thus act as a relevance filter. For instance, experts demonstrated complex knowledge about farming processes, as such understanding is critical for maximizing agricultural yields. In contrast, expert descriptions did not depict the entire complexity of the Aye-ayes' foraging process. Besides the finger being regularly mentioned for food extraction, the use of its teeth and ears and the process of tap scanning (Sterling and McCreless, 2006; Masurkar et al., 2023) were not mentioned. Additional information about the feeding process of Aye-ayes is either not known, or might not seem meaningful for the perception of benefits – a reduction in pests can be perceived without deep knowledge about all ecological interactions involved.

While benefit perception seems to drive the acquisition and retention of knowledge, the importance of knowledge about insectivory for benefit knowledge in the RF-model indicates yet another knowledge-benefit relationship. Knowledge about the Aye-aye's insectivorous diet seems to be essential for the ability to perceive certain benefits in the first place. To be able to relate reductions in pest abundance to the Aye-aye, one has to know that it feeds on larvae. With this ecological understanding, novel information about beneficial ecosystem services can be integrated into the perception of a species (Cebrián-Piqueras et al., 2020; Bhattacharjee et al., 2022).

Coherently, a general environmental understanding is reflected in the knowledge items about the Aye-aye's ecology, which were ranked as important for benefit knowledge in the RF-model. Similarly, medical plant collection, identified as important for benefit knowledge, implies spending time in the forest and requires an understanding of ecological interactions and plant species, too (Evangelista et al., 2024). Gender roles, traditionally associated with males in subsistence societies, appear to be linked to higher environmental knowledge, which may explain the observed relationship between gender and benefit knowledge (Porcher et al., 2022; Schüßler et al., 2019). This interpretation aligns with Randimbiharinirina et al. (2021), who found that high levels of ecological knowledge are associated with stronger perceptions of

benefits, and low knowledge levels relate to holding superstitions (Catapani et al., 2023).

4.3 Sources and transmission of knowledge

In the search for potential knowledge resources, formal education does not appear to be a central factor. The insignificant associations between respondents' formal education levels and ecological knowledge items reflect the marginal representation of environmental aspects in school curricula in Madagascar (Schüßler et al., 2019; Reibelt et al., 2014). Higher identification rates for common and diurnal lemur species and the moderate association between identification knowledge and encounter experience indicate that direct observation is a more relevant source for species recognition. However, the results also suggest that other sources of knowledge are effective for nominal identification and benefit knowledge as 54.6% of respondents demonstrated nominal knowledge and 32.9% showed benefit knowledge without having a prior encounter experience. Direct observation of natural phenomena is an important source of LEK but becomes limited for elusive species (Sheppard et al., 2024). Specifically, the rarity of Aye-aye encounters may not allow for a revision of knowledge coming from direct observations.

Informal transmission was furthermore emphasized as a key source of benefit knowledge and agricultural knowledge in the expert interviews ("I know it from a story"). The acquisition of knowledge through storytelling and participation in daily activities shapes learning processes in subsistence communities (Berkes et al., 2000; Reyes-García et al., 2009). The social transmission of narratives is a very effective channel but is prone to oversimplifying complex ecological realities, leading to the consolidation of misconceptions that might counteract conservation goals (Louder and Wyborn, 2020).

While different sources of knowledge can explain the gap between visual and nominal identification levels, their implications appear more complex. According to Clark and Paivio (1991) dual coding theory, individuals process information through two distinct channels—verbal and visual. In the case of the Aye-aye, knowledge is primarily based on verbal information, such as cultural references, folklore or storytelling. In the absence of visual images, these are enriched by associations the individual has with e.g., other animals or narratives (Lakoff and Johnson, 1980). This could be an explanation for cases in which the Aye-aye's body size is overestimated due to stories about its power. Thus, conservation actions should be mindful of diverse knowledge sources and associations and address ecological knowledge alongside local narratives about the Aye-aye.

4.4 Application and limitations

This study provides valuable insights that help to refine and extend the impact of conservation initiatives, yet several methodological and conceptual limitations warrant discussion. The lack of reliable demographic data from the study area does not allow a quantitative verification of our samples' representativeness. The convenience sampling approach potentially introduced bias, as interviewees were selected based on availability and willingness to participate, possibly favoring those already receptive to conservation topics. Male participants were oversampled due to a high number of refusals from female participants, which were attributed to factors such as shyness or community rules that restrict women from speaking in the presence of men. While we believe this does not substantially affect the information value of our results, it highlights the need for conservation research and actions to be inclusive and mindful of gender equity (e.g., Agarwal, 2009).

The interview process faced inconsistencies, with only two interviews being audio recorded while others relied on written notes due to permission constraints, resulting in varying transcript lengths and potentially affecting data richness. Language translation presented another challenge, as the conversion from Malagasy to English required interpretation beyond literal translation, even with native speaker verification.

The moderate predictive accuracy of our model suggests the influence of unmeasured variables on benefit perception. Important psychological factors known to shape perceptions of contested wildlife species, such as attitudes and behavioral intentions (e.g., Ormsby and Kaplin, 2005), were captured in our survey but were outside the scope of this assessment. Targeted examinations of these factors are currently in preparation to refine how attitudes, behavioral intentions, and knowledge interact in shaping perceptions of the Aye-aye.

Our interview findings, while providing valuable exploratory insights into ecosystem interaction perceptions, should not be extrapolated to draw broad conclusions. LEK systems, though potentially more resistant to quantitative biases due to their focus on interaction quality, could benefit from integration with scientific knowledge to enhance reliability and enable the quantification and modeling of beneficial interactions (Bélisle et al., 2018). A systematic evaluation of ecological interactions and their economic implications, following methods similar to Rodríguez-San Pedro et al. (2020), would provide a deeper understanding of the distribution, scale, and impact of pest control provided by the Aye-aye. Ideally, these are combined with community-based approaches such as participatory mapping (Paudyal et al., 2015).

To mediate social learning, the informal information transfer needs to be carefully aligned to local perceptions. Considering that certain aspects of knowledge were identified as essential to harness the positive effects of high benefit perception, formal education, and educational conservation approaches should aim to establish this knowledge base to foster further knowledge exchange within and between communities (Sheppard et al., 2024; Pilgrim and Pretty, 2010; Jones, 2024). Our survey results also serve as a baseline for evaluating the effectiveness of such educational approaches that aim to improve local land users' knowledge and attitudes about the Aye-aye.

The regional spatial patterns of benefit perception levels remain unclear. Although Randimbiharinirina et al. (2021) reported homogeneous levels of benefit knowledge within communities, our findings show that respondents with benefit knowledge are present in every community, but the proportion varies between communities. Subsection 2 had notably lower knowledge levels, possibly due to coastal-inland trade links eroding local knowledge (Reyes-García et al., 2013; Aswani et al., 2018). Above the regional scale, the Aye-aye's range extends into areas where clove farming is uncommon, making the identified benefits less applicable (Danthu et al., 2014; Louis et al., 2020). We are therefore currently, investigating the regional variability of LEK about the Aye-aye to reveal potential additional beneficial interactions in three other regions along the east coast of Madagascar. Further, our findings on LEK are being integrated into the educational programs of collaborating NGOs. By understanding the sources and transmission channels of benefit knowledge about the Aye-aye we want to enable the utilization of these novel insights into both evidence-based conservation and educational approaches that are tailored to and mindful of the local socio-ecological conditions.

Data availability statement

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

Ethics statement

The study involved human participants and was approved by the Ethics Committee of the University of Hildesheim (Prof. Dr. Peter Cloos, Cloosp@unihildesheim.de). The surveys were conducted in accordance with local legislations and institutional requirements. Due to high illiteracy among participants, we used oral consent and made the basic principles of participation (non-disclosure, voluntarily and confidentiality) transparent beforehand.

Author contributions

HBR: Formal Analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. CB: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. DS: Conceptualization, Funding acquisition, Methodology, Writing – review & editing. YA: Data curation, Formal Analysis, Visualization, Writing – review & editing. JRat: Supervision, Writing – review & editing. JRaz: Supervision, Writing – review & editing. HR: Supervision, Writing – review & editing. TR: Conceptualization, Methodology, Supervision, Writing – review & editing. AM: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. Fieldwork funding was provided by Re:wild/Primate Action Fund (Grant Number: SMACCO-G0000000038) to DS, and by the Rufford Foundation (Rufford Small Grant, Grant Application ID: 39070-1) to HBR. Personal DAAD scholarships were received by CB (Doctorate Short-Term Grant 2023 [57647578] for fieldwork) and HBR (Doctorate Short-Term Grant 2024 [57693450] for data analysis). We acknowledge financial support for publication by the Stiftung Universität Hildesheim.

Acknowledgments

This study was conducted under the research permit No. 057/22/MEDD/SG/DGGE/-DAPRNE/SCBE.Re, kindly issued by the Directeur des Aires Protegées, des Ressources Naturelles Renouvelables et des Ecosystemes and approved by the Direction Régionale de l'Environnement et du Développement Durable (DREDD) in Maroantsetra. We acknowledge Brigitte Raharivololona and the Department for Anthropobiology and Sustainable Development (ADD) from the University of Antananarivo for their assistance during the research permit request. The authors are particularly thankful for the valuable work of Xavier Mamitsara and Theosel Sahidilahy during the interviews and Domenico Randimbiharinirina, Naina R. Rabemananjara and Tahiriniaina Radriarimanga during the pre-testing of interview materials. We thank all local communities that participated in the study for their hospitality, trust, and cooperation and acknowledge the Wildlife Conservation Society Madagascar for providing support during the fieldwork in Makira Natural Park. The Groupe d'Etude de Recherche sur les Primates de Madagascar (GERP) for facilitating the allocation and reception of funds. Maria Jafari provided helpful guidance in the development of the code system and qualitative analysis. The authors also thank Nick Garbutt for providing pictures of the Aye-aye in its natural environment. This study utilized OpenAI's ChatGPT (GPT-4), to assist with refining language during the writing process.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. This study utilized OpenAI's ChatGPT (GPT-4), to assist with refining language during the writing process.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2025.1553217/full#supplementary-material

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