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Perceptions, Knowledge, and Invasion Extent of *Lantana camara* on Household Yards in Rural Communities in Limpopo Province, South Africa

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ABSTRACT

Studies on human perceptions of *Lantana camara* invasion are needed to inform management. This study used a two-pronged approach to assess perceptions, knowledge, and uses of *L. camara* in rural communities as well as evaluate its invasion extent in household yards of the Vhembe Biosphere Reserve, Limpopo province of South Africa. Results from 300 face-to-face household interviews and household ecological surveys showed that most villagers know of *L. camara* but are not aware that it is an invasive alien plant. Both people's responses and ecological household yard surveys show that the plant is on properties and is expanding. Few benefits compared to negative impacts were mentioned. Local communities are implementing control measures; however, they need assistance from the government. The results highlight the need to incorporate local and individual clearing initiatives into the current broader national control programmes, such as the Working for Water clearing programme.

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Introduction

Invasive alien plants (IAPS) are one of the drivers of environmental change (Rai and Singh 2020) and invasion of natural ecosystems has been reported to have detrimental impacts on human well-being (Vardien et al. 2012; van Wilgen et al. 2020a). For most IAPS, invasion success in natural ecosystem is driven by socio-economic and environmental factors, such as globalization, increased human travel, absence of competitors in invaded ecosystems, and climate change (Leishman and Gallagher 2016; Dutta 2018; Shackleton et al. 2020; van Wilgen et al. 2020b). Invasive alien plants are regarded as ecosystem transformers because of their ability to change ecosystem processes and functions (Richardson et al. 2020), through soil manipulation and the creation of monostands that result in the displacement of native species (Simberloff et al. 2013; Richardson et al. 2020). For example, the introduction of Australian *Acacias* in South Africa is associated with negative effects on soil physio-chemical properties resulting

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in displacement of native vegetation (Le Maitre et al. 2011), whereas *Eucalyptus* invasions are linked with the creation of monospecific stands with little understory native vegetation (Hirsch et al. 2020). The proliferation of IAPS, such as *Pinus*, *Acacias*, and *Eucalyptus* along South African riparian zones is associated with significant loss of river water (Richardson et al. 2020; van Wilgen et al. 2020a). Recent studies (e.g., Haubrock et al. 2021; Bang et al. 2022; Eschen et al. 2021; Fantle-Lepczyk et al. 2022) have shown that invasion by IAPS causes significant effects on global economies, with effects likely to be substantial in the agricultural sector. For example, Eschen et al. (2021) reported that the total annual cost of invasive alien species (IAS) to Africa's agricultural sector is ~ US$65.58 billion. Although social effects linked to IAS are difficult to quantify due to potential benefits, some studies (e.g., Ngorima and Shackleton 2019; Shackleton et al. 2020) have reported that poor rural households are the most affected due to their dependence on natural ecosystems for livelihoods. Therefore, more research is needed on socio-economic impacts of IAS in rural communities (Shackleton et al. 2020).

Research on invasion pathways and traits is instrumental in developing adaptive management strategies aimed at reducing invasion impacts and costs (Faulkner et al. 2020). However, most research on biological invasion is ecological, thus omitting understanding of the social dimension that has the potential to inform management interventions since most IAPS are moved by humans (Sundaram et al. 2012; Shackleton et al. 2017a, 2017b). Studies (e.g., Shackleton et al. 2007; Rai et al. 2012; Shackleton et al. 2017a, 2017b; Ngorima and Shackleton 2019) that assess perceptions, knowledge, and practices related to IAPS often highlight key aspects, such as benefits, costs, invasion drivers, and attitudes toward these species. These studies (e.g., Shackleton et al. 2017a, 2017b; Zengeya et al. 2017; Ngorima and Shackleton 2019) can provide important information on costs and benefits that can be used to manage IAPS, especially conflict generating species—which are viewed as having both costs and benefits to humans. For example, social studies (e.g., Jevon and Shackleton 2015; Shackleton, Le Maitre, and Richardson 2015; Shackleton et al. 2017a, 2017b) on *Prosopis* (mesquite), *Lantana*, and *Chromolaena* invasion in Africa have shown that these species provide important rural livelihood benefits, such as fodder and fuelwood to the extent that removal can cause conflict with users, who are also aware of the negative impacts of the species. Similarly, Ruwanza and Thondhlana (2022) highlighted that *Psidium guajava* is extensively used by villagers and has several benefits, so its removal needs stakeholder engagement to avoid conflicts. Given that some IAPS offer both costs and benefits there is a need to gather data on human perceptions to develop effective management strategies. Therefore, social studies can provide evidence that invasion biologists need to understand invasion science from a socio-ecological perspective if interventions to manage IAPS are to yield positive outcomes.

Human perceptions toward IAS are shaped by several factors that include individual human attributes, characteristics of the IAS, accrued costs and benefits, social, cultural, landscape, institutional, and policy context (Shackleton et al. 2019a). For example, *Opuntia ficus-indica* has several economic benefits to rural villagers in Eastern Cape Province of South Africa, thus local people view it positively with little efforts to remove the plant (Shackleton, Kirby, and Gambiza 2011). Similarly, *Eucalyptus camaldulensis* generates a lot of income for the bee industry in South Africa to the extent that removal is mainly along sensitive ecosystems like riparian zones, rather than in bee industry hotspot farms (Hirsch et al. 2020). Besides *L. camara* being one of the main invaders in South Africa, little is known regarding human perceptions toward its invasion. The few studies (e.g., Jevon and Shackleton 2015) conducted on *L. camara* in South Africa have indicated that local villagers know about the plant and are aware of its costs and benefits. However, human perceptions vary depending on the landscape, demographic, and socio-cultural changes, thus the need to conduct more research on *L. camara* to develop a holistic picture that can be used for developing adaptive interventions. Therefore, understanding *L. camara* invasion from a social standpoint can help explain some difficulties linked to its management as well as generate relevant information that can be used to manage the plant effectively.

The control and management of IAS in South Africa are mostly done by the Working for Water (WfW) programme (van Wilgen et al. 2012, 2020b). The WfW programme is a government funded programme, which was established in 1995 with the aim of controlling IAS through employing previously disadvantaged communities to remove IAS, thus creating employment (van Wilgen et al. 2012, 2020b). The programme spends ~2 billion Rands per year on IAPS clearing and the most used clearing method is slash and stack burning (van Wilgen et al. 2020b). In spite of achieving some clearing success (e.g., clearing around 200 000 consolidated hectares per year), the programme has faced challenges, such as conflicts related to removing species that are perceived to be beneficial to some sectors of society (van Wilgen and Wannenburgh 2016; van Wilgen et al. 2020b), such as attempts to clear *E. camaldulensis* in bee industry hotspots which have triggered conflicts as the plant is perceived beneficial (Hirsch et al. 2020). It is not clear how society perceives the removal of *L. camara* by WfW, yet its successful management needs to be shaped by human perceptions, thus the need to conduct this study on the human dimension of biological invasion.

Lantana camara (commonly known as *Lantana*) is one of the world's worst invasive shrubs ranked among the top 100 invaders (Taylor and Kumar 2013). Similar to other aggressive IAPS, *L. camara* has adverse impacts on biodiversity, ecosystem functions, and human well-being (Day and Neser 2000; Vardien et al. 2012; Bang et al. 2022). *Lantana camara* is a thorny, multi-stemmed shrub that consists of many hybrids (Vardien et al. 2012). In conducive environments, the plant flowers throughout the year (Sharma, Raghubanshi, and Singh 2005) and can reach an average height of 1.8 m (Vardien et al. 2012). The plant thrives in the tropics and subtropics region as well as the temperate region and invades various habitats, such as disturbed habitats (e.g., old fields and road networks), moist habitats (e.g., riparian zones), and less disturbed habitats (e.g., protected national parks) (Sharma, Raghubanshi, and Singh 2005; Barahukwa et al. 2023). Its introduction across many global regions has been human-aided, mostly for ornamental purposes, although the dispersal of seeds by birds has been noted (Sharma, Raghubanshi, and Singh 2005). In South Africa, the species was introduced around the 1850s and it is currently listed as a category 1b invader, meaning trade, planting, and possession of *L. camara* is prohibited and where possible the plant should be removed (NEMBA Act 10 of 2004). To date, *L. camara* has invaded over 2 million hectares of land in South Africa, and impacts include the loss of native biodiversity and agricultural land resulting in reduced crop yields and income (Jevon and Shackleton 2015; Vardien et al. 2012). Although *L. camara* has several benefits, such as medicinal, making baskets, furniture, ornamental and use as a hedge (Kannan, Shackleton, and Shaanker 2014; Vardien et al. 2012), some studies (e.g., Shackleton et al. 2017a; Barahukwa et al. 2023) have acknowledged that the negative impacts associated with *L. camara* invasion seem to outweigh these benefits.

The integration of human perceptions and ecological surveys is important as it balances social, economic, and environmental concerns to try and understand global environmental problems, such as invasion by IAPS like *L. camara*. Such integration can result in a better understanding of ecosystem regime shifts and systems dynamics linked to IAPS at the landscape level. Knowledge generated from such integrative studies is crucial in developing appropriate IAPS response strategies. Considering this context, we aimed to assess human perceptions, knowledge, and uses of *L. camara* in rural communities in Vhembe Biosphere Reserve, Limpopo Province of South Africa. Specifically, we used a two-pronged approach to examine invasion perceptions and extent on household yards. The two-pronged approach included (i) face-to-face household interviews to solicit local knowledge, perceptions, and uses of *L. camara* by the rural communities, and (ii) detailed vegetation surveys on all household yards to gather information on invasion extent within each household yard.

Methods

Human Ethics

The research was in accordance with Rhodes University Ethical Standards guidelines and only commenced after it was approved by the university human ethics committee (Rhodes University Ethics Number 2019-0795-799). Before the research study commencement, permission was sought from all six village leaders and ward councilors. Before conducting household interviews, informed consent was obtained following a detailed explanation of the study objectives to the respondent. Confidentiality assurance and response anonymity were explained to all respondents before conducting the interview. Participation was voluntary and the right to participation withdraw at any given time without penalty was granted. Also, participants had the right to decline responses to a particular question that they were not comfortable with. In this study, no personal information was collected, and data were anonymized through assigning numbers to every questionnaire.

Study Area

Household interviews were conducted in six villages that are in the Vhembe Biosphere Reserve, Limpopo Province of South Africa (Figure 1). The six villages are Duthuni (22.9722°S, 30.3810°E), Tshakhuma (23.0441°S, 30.3001°E), Murunwa (22.9816°S, 30.1633°E), Matshavhawe (22.9755°S, 30.1026°E), Ha Mutsha (23.0512°S, 30.3599°E), and Ha Maelula (22.9831°S, 30.1402°E) (Mhlongo 2021). Besides Duthuni which is in the Thulamela Municipality, all other villages are in Makhado Municipality. The population sizes of the villages range from 207 (Ha Mutsha) to 6 345 (Duthuni), with most people heavily dependent on subsistence farming and government social grants (Stats SA (Statistics South Africa) 2011). The villages are in Soutpansberg Mountain

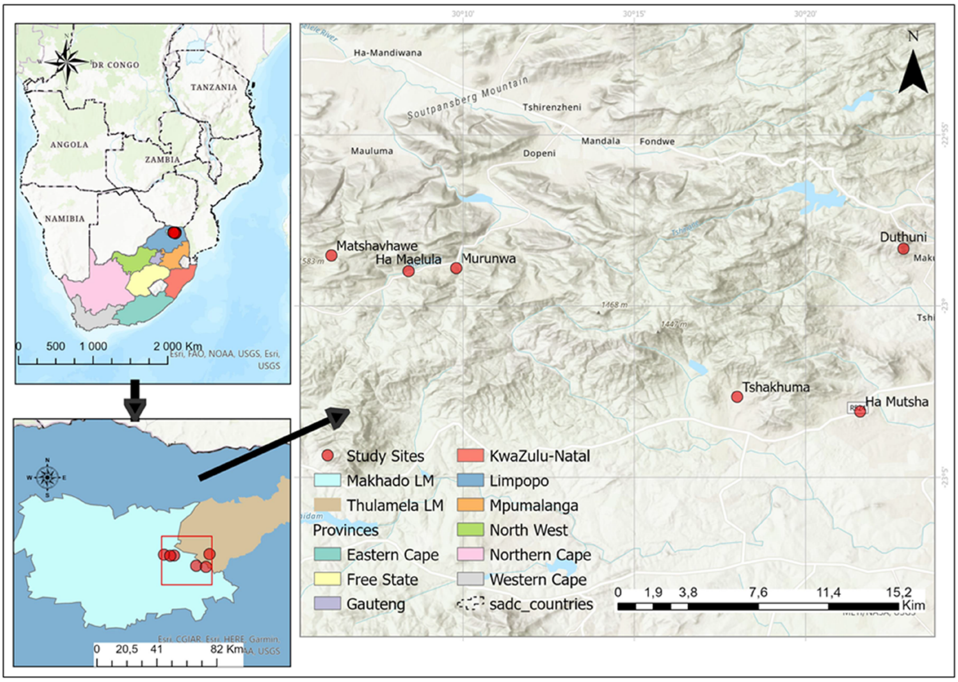

Figure 1. Location of the six study villages in Vhembe Biosphere Reserve, Limpopo Province of South Africa.

Bushveld vegetation (Mucina and Rutherford 2006) comprising of dense trees and shrubs, such as *Vachelia karoo*, *Catha edulis*, *Berchemia zeyheri*, *Bridelia mollis*, *Searsia magalismontana*, and *Helichrysum kraussii* with a poorly developed grassy layer understory (Mucina and Rutherford 2006). The mean annual precipitation is ~1050 mm and most of the rain falls in austral summer (October to March). Temperatures are hot in summer (averaging 28 °C) and mild in winter (averaging 18 °C), whereas soils are generally clay with high acidic content (Mucina and Rutherford 2006).

Household Interview Surveys

The six villages were selected because observations during a 2019 reconnaissance study showed that most household yards were dominated by *L. camara*. Within each village, 50 face-to-face household interview surveys were conducted in 2019, with purposive sampling being used to select the households (Mhlongo 2021). A household was selected for interview if *L. camara* was present in the homestead and if the household had knowledge of the plant. Knowledge of the plant was assessed by showing the respondent a picture panel of the plant and a plant sample in their yard. Although purposive sampling has selection bias, it was preferred to limit the respondents to those who have the plant in their household yards and have knowledge of the plant. Also, by purposively selecting respondents who have the plant in their household yard, it created conditions for ecological data to be collected. At each selected household one adult member was interviewed, and interviews were conducted during weekdays between 08h00 and 16h00 using the local Tshivenda language. Each interview took approximately an hour, and interviews were conducted with the assistance of a local researcher who could speak the language (Mhlongo 2021).

The questionnaire consisted of four sections, with the first section gathering information on knowledge and perceptions regarding *L. camara*. The questions on knowledge and perceptions gathered information on invasion introduction and extent of properties. The second section gathered information on *L. camara* benefits and negative impacts that villagers experienced. Perceived benefits and negative impacts were identified by asking each respondent to indicate either *L. camara* is harmful, beneficial, has no impact, or both beneficial and harmful (Shackleton, Le Maitre, and Richardson 2015). The third section gathered information on the management of the plant, with questions gathering information on methods of controlling *L. camara* at the household level as well as the type of management support that respondents are receiving. The last section gathered information on the demographics of the respondents (see Supplementary Appendix S1 for interview guide).

Household Yard Ecological Surveys

Ecological surveys were conducted at each household yard were face-to-face interviews were conducted by counting all the *L. camara* shrubs present in the yard (Mhlongo 2021). For each counted *L. camara*, plant height and canopy cover were measured using a tape measure, whilst plant basal diameter was measured using a Vernier caliper. Canopy cover was measured using the plant's widest canopy area of influence, by placing a tape measure from one edge of the tree crown to another edge through the crown center. For multi-stemmed plants, the diameter of all stems was measured and averaged to represent the plant's diameter (Mhlongo 2021).

Data Analysis

Responses from all household interviews were grouped into emerging themes aimed at describing villagers' knowledge, perceptions, impacts (both positive and negative), and management interventions. Thematic analysis was used to identify the perceived impacts (both positive and negative) and management options of *L. camara*. Descriptive statistics were used to show the distribution of data and the proportion of responses across villages using tables and figures. Chi-Square tests (χ^2) were conducted to assess responses on *L. camara* knowledge, perceptions, impacts (both positive and negative), and management across the different villages.

The ecological data from household yard surveys were analyzed using one-way analysis of variance (ANOVA) to compare vegetation measurements across the six villages. Where significant differences were observed, a Tukey-HSD homogenous *post-hoc* test was used to assess differences across villages. Proof of normality and homogeneity of variances were tested using the Kolmogorov-Smirnov tests and Levene's tests, respectively, and data were normally distributed. Multiple regression analysis was conducted to assess the relationship between some social factors (i.e., age, gender, education level, household income, *L. camara* occurrence levels, *L. camara* impact levels, spread at the household level, spread in the area, and management responses) on ecological household yard data (*L. camara* abundance, height, diameter, and canopy cover). Data for these social factors was obtained from household interview responses. We acknowledge that the above-mentioned social data was collected using purposive sampling, therefore regression analysis results could limit our understanding of the patterns within the responses since our social data was not a reflection of the entire community. Regardless of the above shortcomings, the social data gathered from interview responses was used because previous studies have shown that these indicators can influence species abundance and spread (Thondhlana and Ruwanza 2020; Choksi et al. 2023). All statistical analyses were performed using STATISTICA version 14.0 software (TIBCO Software Inc 2019).

Results

Demographics of the Sample Population

Most of the respondents across all villages were female (70%), with Matshavhawe village having a high number of females (88%) (Table 1). The average number of people per household across all villages was seven, being high in Matshavhawe and low in Duthuni and Tshakhuma villages (Table 1). The dominant age range across all villages was 61–70 years. The age range of 21–30 years had the least number of respondents (3%) across all villages. Like most rural communities in South Africa, most respondents (36%) across all villages had a primary education level, with more than half of them being in Matshavhawe village (Table 1). Across all villages, only a handful of the respondents had a university education. Across all villages, most respondents were dependent on social grants and formal employment (Table 1).

Knowledge and Perceptions of L. camara

All the respondents (100%) in Tshakhuma, Matshavhawe, and Ha Mutsha did not plant *L. camara* on their properties, however, few respondents in Duthuni (4%), Murunwa (2%), and Ha Maelula (2%) planted *L. camara* on their properties, though these results showed no significant differences ($\chi^2 = 23.1$, $p > 0.05$; Table 2). Most of the villagers who did not plant *L. camara* said it germinated naturally on the property (82%), with the remainder stating that they found it present when they moved onto the property. Although few respondents (26%) across all villages reported that *L. camara* was spreading on their properties, most respondents (46%) noted that the plant was spreading in the area (Table 2). Of those who noted *L. camara* spread in the area, more than half were in Tshakhuma (64%), Murunwa (54%), and Ha Mutsha (56%), and statistical comparisons across villages showed significant differences ($\chi^2 = 47.4$, $p < 0.001$; Table 2). Few respondents (35%) across all villages knew that *L. camara* is an IAPS, with most people being in Matshavhawe (64%) and Tshakhuma (40%). Comparisons across all villages showed significant differences for those who knew *L. camara* invasion status ($\chi^2 = 47.4$, $p < 0.001$; Table 2). Respondents were asked about the level of *L. camara* occurrence on their property and most of them reported scarce (47%), very scarce (29%), and moderate (21%) occurrences across all villages (Figure 2). The bulk of the respondents who reported very scarce occurrences were in Duthuni (50%), whereas those who recorded scarce occurrences were in Murunwa (63%) and Matshavhawe

Table 1. Demographics of the sampled population in six villages located in Vhembe Biosphere Reserve, Limpopo Province of South Africa.

	Duthuni	Tshakhuma	Murunwa	Matshavhawe	Ha Mutsha	Ha Maelula	Mean
Mean number of people per hh	6	6	7	9	8	7	7
Gender (% of adult females)	52	68	78	88	62	72	70
Racial group (% of black)	100	100	100	100	100	100	100
Age range (% of respondents)							
21–30	3	4	4	1	3	1	3
31–40	2	10	5	6	4	4	5
41–50	13	4	7	7	4	6	7
51–60	9	5	15	13	11	13	11
61–70	8	11	14	11	19	13	13
Above 71	18	16	5	12	8	13	12
Level of education (% of respondents)							
University education	6	12	6	4	4	0	5
Matric level	22	22	14	8	28	14	17
High school	10	18	18	16	10	14	14
Primary education	44	8	40	52	32	38	36
No formal education	18	40	22	20	26	34	27
Income (% of respondents)							
Social grant	27	22	22	21	18	29	23
Formally employed	8	20	21	20	18	15	17
Self employed	10	5	3	4	6	6	7
Pension	0	1	0	3	2	0	1

Table 2. Respondents' responses to questions relating to knowledge and perceptions of *Lantana camara* across the six villages in Vhembe Biosphere Reserve.

	Duthuni	Tshakhuma	Murunwa	Matshavhawe	Ha Mutsha	Ha Maelula	Mean	χ^2
Do you know *L. camara* (% yes)	100	100	100	100	100	100	100	–
Do you have it on your property? (% *Yes*)	100	100	100	100	100	100	100	–
Did you plant *L. camara* on your property? (% *Yes*)	4	0	2	0	0	2	1	23.1ns
Is it spreading on your property? (% *Yes*)	29	18	24	12	42	30	26	20.0ns
Is it spreading in the area? (% *Yes*)	30	64	54	42	56	30	46	47.4***
Are you aware it is an invasive alien species (% *Yes*)	29	40	20	64	20	36	35	29.7***

Data are average percentages of respondents and $n = 50$ per village.
***$p < 0.001$, [ns]not significant at $p > 0.5$.

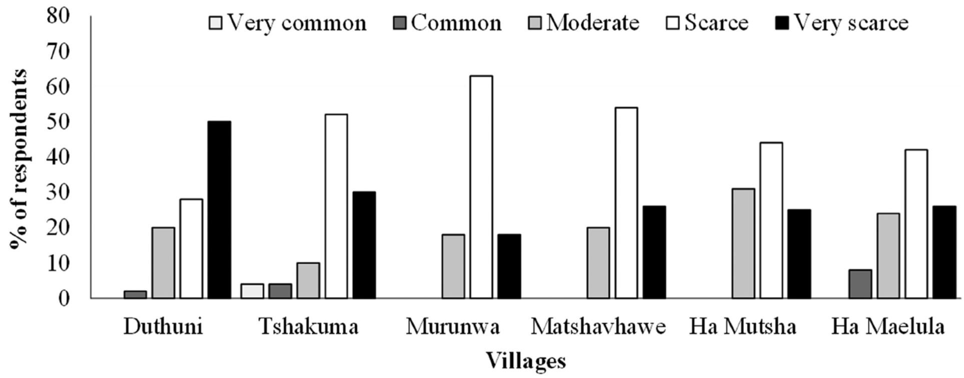

Figure 2. Community responses to questions related to *Lantana camara* occurrence on household properties located in Vhembe Biosphere Reserve. Bars are average percentages of respondents and $n = 50$ per village.

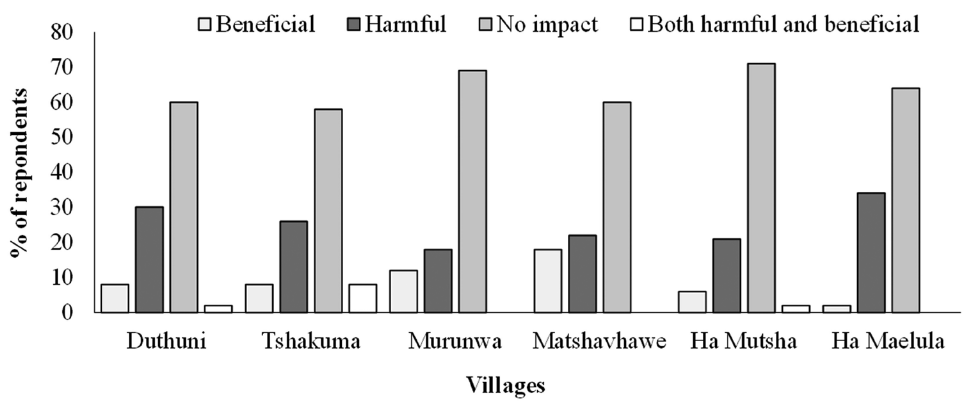

Figure 3. Community responses to questions related to *Lantana camara* impacts in Vhembe Biosphere Reserve. Bars are average percentages of respondents and $n = 50$ per village.

(54%; Figure 2). Only a few respondents in Tshakuma (4%) reported very common occurrences on their properties (Figure 2).

Benefits and Negative Impacts of L. camara

Most respondents in Duthuni (60%), Tshakhuma (58%), Ha Maelula (64%), Murunwa (69%), Matshavhawe (60%), and Ha Mutsha (71%) were of the view that *L. camara* had no impact on their livelihoods. No significant differences ($\chi^2 = 6.1$, $p > 0.05$) were observed in their responses with regard to impacts on livelihoods. Across all villages, only 25% of the respondents thought that *L. camara* is harmful and only 9% of the respondents highlighted it was beneficial (Figure 3). Most of the respondents who view *L. camara* as harmful were in Ha Maelula (34%), whereas those who view it as beneficial were in Matshavhawe (18%; Figure 3). Respondents were asked to list *L.*

camara benefits and few respondents listed medicinal (6%; $\chi^2 = 11.9$, $p < 0.05$) and fruit consumption (9%; $\chi^2 = 21.6$, $p < 0.05$), and these benefits showed significant differences across villages. The most common medicinal benefits stated by respondents were the treatment of sore eyes and teeth as well as the treatment of colds and fevers. The remainder of the benefits, such as fence/hedge, ornamental, and mosquito repellent were mentioned by <5% of the respondents across all the villages, and these showed no significant differences ($p > 0.05$; see Table 3 for χ^2 values). A total of eight negative impacts associated with *L. camara* were listed by the respondents, with the plants pricking thorns, toxic to livestock when grazed, and the ability to outcompete native vegetation for resources being listed by more than 10% of the respondents across all villages (Table 3). All these negative impacts showed significant differences across villages ($p < 0.001$; see Table 3 for χ^2 values). Negative impacts, such as causing skin irritation, the proliferation of *L. camara* as a weed everywhere, its bad odor, water extraction, and ability to harbor snakes were mentioned by <10% of the respondents across all villages (Table 3). Statistical comparisons of the above-mentioned negative impacts across all villages showed significant differences ($p < 0.05$; see Table 3 for χ^2 values).

Management of L. camara

The majority of the respondents (76%) across all the villages would be happy to see a decrease in *L. camara* in the area, although results showed no statistical differences ($\chi^2 = 18.5$, $p > 0.05$; Table 4). Similarly, most of the respondents across all the villages manage the plant on their properties, and results showed significant differences across villages ($\chi^2 = 25.8$, $p < 0.001$; Table 4). Respondents were asked to elaborate on how they manage the plant on their property and most of the villagers (98%) across all villages were cutting the plant near the base using axes and burning the plant residues, with only a few villagers (2%) using chemicals to control *L. camara*. Those who do not use chemicals to control the plants listed cost as a barrier to adopting the chemical control method. Only a handful of respondents (5%) across all villages have received information regarding the management of IAPS from tribal gatherings and through word of mouth from fellow villages who mostly interact with the WfW programme, and results showed significant differences ($\chi^2 = 20.1$, $p < 0.001$) across villages (Table 4). The bulk of those who received management information are in Tshakhuma (18%), with those in Matshavhawe (0%) highlighting that they received no information at all. A few of the respondents in Tshakhuma (10%), Murunwa (6%), Ha Maelula (6%), and Ha Mutsha (2%) stated that they have received assistance from government to manage *L. camara* (Table 4). The WfW programme was cited as the main organization responsible for assisting in managing *L. camara*, with assistance mostly being information on how to manage the plant. Most respondents (67%) across all villages highlighted that they want assistance (i.e., tools, chemicals, and clearing employment contracts) from the government (Table 4). Although results showed no significant differences across villages ($\chi^2 = 7.3$, $p > 0.05$), most respondents who wanted assistance were in Duthuni (72%), Ha Maelula (72%), and Murunwa (61%).

Table 3. Respondent's views of the benefits and negative impacts of *Lantana camara* across the six villages in Vhembe Biosphere Reserve.

	Duthuni	Tshakhuma	Murunwa	Matshavhawe	Ha Mutsha	Ha Maelula	Mean	χ^2
Benefits								
Medicinal	6	8	4	8	2	0	6	11.9*
Fruit consumption	8	6	8	12	0	0	9	21.6***
Fence/Hedge	4	2	0	0	4	2	3	8.2ns
Ornamental	0	0	0	0	0	2	2	10.0ns
Mosquito repellent	0	0	0	2	2	0	2	8.1ns
Preservative	0	0	0	0	2	0	2	10.0ns
Negative impacts								
Pricking thorns	6	8	14	6	12	22	11	18.8**
Causes itchiness to skin	0	0	4	4	0	14	7	41.7***
Toxic to livestock	4	0	8	20	8	12	11	21.9***
Bad odor	0	0	2	0	4	4	3	11.8*
Grows as a weed everywhere	2	2	2	0	2	8	3	14.4**
Extracts water from soils	4	10	0	0	0	0	7	36.6***
Harbours snakes	4	8	0	0	2	2	4	17.5**
Outcompetes native vegetation for resources	20	12	0	0	4	6	11	46.9***

Data are average percentages of respondents and $n = 50$ per village.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, ^{ns}not significant at $p > 0.5$.

Table 4. Perceptions on management of lantana camara across the six villages in Vhembe Biosphere Reserve.

	Duthuni	Tshakhuma	Murunwa	Matshavhawe	Ha Mutsha	Ha Maelula	Mean	χ^2
Would you be happy if *L. camara* decreased in your area? (% yes)	76	68	86	62	81	84	76	18.5ns
Do you manage the plant on your property? (% yes)	92	96	67	70	65	80	78	25.8***
Do you receive any information regarding management of IAP? (% yes)	4	18	4	0	4	2	5	20.1***
Do you receive assistance from government in managing the plant? (% yes)	0	10	6	0	2	6	4	10.3ns
Would you like the government to assist you in managing *L. camara*? (% yes)	72	64	61	70	65	72	67	7.3ns

Data are average percentages of respondents and $n = 50$ per village.
***$p < 0.001$, ^ns^not significant at $p > 0.5$.

The Influence of Social Factors on L. Camara Invasion Extent

The average abundance of *L. camara* at each household property ranged from 2.1 ± 0.39 trees (Tshakuma) to 2.6 ± 0.19 trees (Ha Mutsha), and there were no significant differences across all villages (ANOVA, $F = 0.737$, $p = 0.596$). The height of *L. camara* in all properties across all villages averaged 1.31 ± 0.06 m. Although average plant height was slightly high in Ha Mutsha (1.36 ± 0.04 m) compared to Duthuni (1.25 ± 0.05 m), no significant differences (ANOVA, $F = 1.114$, $p = 0.351$) were observed across villages. In contrast, both *L. camara* diameter (ANOVA, $F = 4.956$, $p < 0.001$) and cover (ANOVA, $F = 14.045$, $p < 0.001$) were significantly different across all the villages, with large and tall trees recorded in Tshakhuma compared to Ha Mutsha. Overall, the regression model explained <10% of the variance in *L. camara* abundance (8%), height (2%), diameter (3%), and canopy cover (3%; Table 5), an indication that the social factors had little influence on *L. camara* ecological data. However, a closer examination of the regression model shows that only household income, *L. camara* occurrence, and impact levels showed significant negative regression coefficients with *L. camara* abundance (Table 5). This implies that respondents who received social grants recognized the increase in *L. camara* abundances as compared to pensioners. Also, respondents who said *L. camara* is very common and beneficial noted an increase in its abundance. Only, one factor (i.e., *L. camara* impact levels) showed a significantly negative relationship with species height, meaning respondents who said *L. camara* is beneficial noticed its increase in height. From a diameter standpoint, households who reported *L. camara* as a commonly occurring species with benefits tend to notice its increase in diameter (Table 5). Only respondent age and income showed a significantly negative regression coefficient with *L. camara* cover. The above-mentioned result implies that young respondents were likely to notice an increase in *L. camara* cover compared to older respondents who noticed an inverse relationship. Also, social grant recipients noticed an increase in plant cover compared to pensioners.

Discussion

We used a two-pronged approach to assess perceptions, knowledge, uses, and *L. camara* invasion extent in six rural communities located in the Vhembe Biosphere Reserve, Limpopo Province of South Africa. Most of the villagers are familiar with *L. camara* but do not know that it is an IAPS that can transform the ecosystem. Previous studies (e.g., Shackleton et al. 2019a; Ruwanza and Thondhlana 2022) have reported that knowledge about IAPS by local rural communities is linked to numerous factors like benefits, invasion extent, and history. For example, it has been reported that IAPS, such as *Acacia dealbata* (Ngorima and Shackleton 2019) and *P. guajava* (Ruwanza and Thondhlana 2022) are perceived as native species by rural communities due to livelihood benefits. In other studies, IAPS with a long duration in an area is regarded as native by local communities (Shackleton et al. 2019a). This is more applicable in areas with harsh climatic conditions, such as semi-arid regions where IAPS that were introduced a long time ago now dominate the landscape compared to native species which naturally have low densities (Shackleton and Shackleton 2018). Our study species (i.e., *L. camara*) was introduced in South Africa around 1850s and now invades more than

Table 5. Multiple regression results showing the influence of social responses on ecological data, namely *Lantana camara* abundance, height, diameter, and cover.

	L. camara abundance			*L. camara* height			*L. camara* diameter			*L. camara* cover		
	Beta (β)	SE	*t*-Value	Beta (β)	SE	*t*-Value	Beta (β)	SE	*t*-Value	Beta (β)	SE	*t*-Value
Age of respondent	−0.081	0.078	−1.032ns	−0.070	0.081	−0.863ns	−0.074	0.080	−0.926ns	−0.167	0.080	**−2.081***
Gender of respondent	0.023	0.060	0.377ns	0.032	0.062	0.525ns	−0.012	0.061	−0.193ns	0.092	0.061	1.498ns
Education level	0.116	0.076	1.535ns	0.059	0.078	0.749ns	0.064	0.078	0.830ns	0.019	0.078	0.241ns
Household income	−0.215	0.065	**−3.291*****	−0.120	0.068	−1.768ns	−0.164	0.067	**−2.446****	−0.160	0.067	**−2.377***
Occurrence levels	−0.139	0.062	**−2.258***	−0.070	0.064	−1.102ns	−0.148	0.063	**−2.335***	−0.063	0.063	−0.991ns
Impact levels	−0.137	0.060	**−2.287***	−0.143	0.062	**−2.314***	−0.066	0.061	−1.081ns	−0.106	0.061	−1.733ns
Spread at household	0.018	0.061	0.300ns	−0.041	0.064	−0.647ns	−0.126	0.063	**−1.993***	−0.111	0.063	−1.753ns
Spread in the area	−0.091	0.059	−1.548ns	−0.080	0.061	−1.320ns	−0.024	0.060	−0.402ns	−0.072	0.060	−1.196ns
Management	−0.093	0.058	−1.606ns	−0.049	0.060	−0.822ns	0.044	0.060	0.739ns	0.034	0.060	0.567ns
R^2			0.112			0.052			0.062			0.064
R^2 adjusted			0.083			0.020			0.031			0.033
F value			3.800			1.647			1.991			2.056
p-Value			<0.001			0.102			0.040			0.034
SEE			0.387			0.928			0.719			1.178

SE: standard error.
Bold values indicate significant differences at $p < 0.05$.
Notes:
Age = 21–30 (1), 31–40 (2), 41–50 (3), 51–60 (4), 61–70 (5), >71 (6).
Gender = Male (0), Female (1).
Education level = No formal education (1), Primary (2), High school (3), Matric (4), University (5).
Household income = Social grant (1), formally employed (2), self-employed (3), pension (4).
Occurrence level = Very common (1), common (2), moderate (3), scarce (4), very scarce (5).
Impact levels = Beneficial (1), harmful (2), no impact (3), both beneficial and harmful (4).
Spread at household = No (0), yes (1), don't know (2).
Spread in the area = Decrease (0), increase (1), stay the same (2), don't know (3).
Management = No (0), yes (1).

2 million hectares (Vardien et al. 2012), thus its long history in the environment could result in most villagers viewing it as native since it is now integrated within the natural environment. This observation is consistent with Ngorima and Shackleton (2019) who reported that *A. dealbata* long history in the Eastern Cape Province of South Africa has resulted in local people regarding it as native.

A third of the respondents reported that *L. camara* is spreading both within household properties and in the greater region. The view that *L. camara* is spreading has been reported in previous studies in South Africa (e.g., Jevon and Shackleton 2015) and globally (e.g., Sundaram et al. 2012; Shackleton et al. 2017a). Jevon and Shackleton (2015) reported that respondents in Mazeppa Bay, Eastern Cape Province of South Africa reported low abundances of *L. camara* in the 1960s but noted increased spread over time. Also, villagers in the above-mentioned study reported that *L. camara* spread was associated with increased loss of non-timber forest products and agricultural land which subsequently resulted in loss of livelihoods. In India, Sundaram et al. (2012) reported that *L. camara* was spreading in the Soliga village and community members attributed the spread to the plants prolific fruit output, seed dispersal, and changes in fire regimes. Indeed, several studies have shown that *L. camara* spread is linked to both species and ecosystem traits. For example, Ruwanza and Shackleton (2016) reported that *L. camara* has an ability to manipulate some soil properties, such as total carbon and phosphorus to enhance its spread. A bioclimatic modeling study by Vardien et al. (2012) showed that Limpopo province, where this study was conducted, provides suitable environmental conditions for *L. camara* spread. The above-mentioned observation was also reported by Subhashni and Lalit (2014) who concluded that current and future climatic conditions in Limpopo province are suitable for *L. camara* spread. Therefore, views by local communities in this study that suggested that *L. camara* is spreading concur with the above-mentioned climatic modeling research.

The benefits associated with *L. camara* were reported by few villages. Benefits were more around provisional services, such as medicinal, fruit consumption, fence, and mosquito repellent. Jevon and Shackleton (2015) in the Eastern Cape Province of South Africa confirmed that *L. camara* has no substantial uses amongst rural communities, with few uses, such as eating ripe fruits and the addition of leaves to food to improve taste. The above-mentioned study suggested that the growing of *L. camara* as a fence/hedge seems to be by chance and people hardly plant it on their property as was observed in this study. In other areas, such as India, *L. camara* has many benefits and economic uses, e.g. medicinal, ornamental, mulching, and biomonitoring indicators for air quality (Negi et al. 2019).

Although respondents listed several negative impacts associated with *L. camara*, the proportion of people who mentioned the negative impacts was relatively small with impacts, such as pricking thorns, toxic to livestock, and ability to outcompete native vegetation being mentioned by more than 10% of the respondents across all villages. In Uganda, Shackleton et al. (2017a) reported that *L. camara* has negative effects on livestock by hindering their movement, whereas Machado et al. (2023) reported that direct consumption of the plant by animals may result in death, reduced fecundity, and animal sickness. Effects on livestock have a significant bearing on rural people's livelihoods as most people are dependent on livestock production and use cattle for cultivation purposes. It has been noted that *L. camara* invasion can reduce livestock forage by 50% and crop yields by 26–50%, resulting in substantial household income losses (Shackleton et al. 2017a). The ability of *L. camara* to outcompete native species for resources has been reported in the past. For example, *L. camara's* ability to outcompete native plants has been attributed to several direct and indirect factors, such as its ability to alter soil nutrient content to its advantage, creation of monostands, altering fire intensity, and high-water uptake at the expense of neighboring plants (Turner and Downey 2010). Also, *L. camara* is allelopathic and releases allelochemicals (e.g. phenolic compounds and triterpenes) that suppress germination and growth of other plants (Kato-Noguchi and Kurniadie 2021). It is important to note that perceptions regarding the negative impacts of plant invasion differ between communities and managers/ecologists, an indication that management could be difficult in cases where views are conflicting, this is also suggested by Zengeya et al. (2017) who forged the term "conflict generating species" to refer to species that have both costs and benefits.

Although both benefits and negative impacts were mentioned by some villagers, a closer look at our results seems to suggest that *L. camara* benefits are few compared to negative impacts an indication that negative impacts might be outweighing benefits. If our above observation based on these results is correct, then management of *L. camara* should be relatively easy given that the plant has few benefits to the community. In any case, we reported that villagers are cutting the plant to control it. *Lantana camara* seems to have more costs than benefits and it is spreading, implying that the costs are likely to increase in the future, thus effects on human livelihoods could increase. From a management standpoint, some studies have shown that IAPS with few benefits are easy to manage because there will be less conflicts among stakeholders (Zengeya et al. 2017; Shackleton et al. 2019a).

Local people are trying to manage *L. camara*, however our results showed that they lack support. Most of the interviewed respondents were controlling *L. camara*, a result that is similar to efforts by community members in Uganda who are managing the plant at the local level (Shackleton et al. 2017a). Local people are managing *L. camara* by cutting it near the base using an ax and burning the residual once dry (Mhlongo 2021), a popular and cheap method used globally (Sharma, Raghubanshi, and Singh 2005; Sundaram et al. 2012; Shackleton et al. 2017a). However, if cut and burn is not done properly there exists a potential that the plant will resprout and grow back, therefore this speaks to the need to educate local people on effective methods to manage the plant. On the other hand, our results showed that villages hardly get the much-needed knowledge and information about the plant, as this is hardly given to them. Lack of information, knowledge, or any form of community assistance to manage IAPS has been noted in the past (e.g., Ngorima and Shackleton 2019). Respondents indicated the need for government assistance and support (e.g. clearing tools) to help them manage *L. camara*. Indeed, the WfW programme does most of the clearing, however, it is not possible for them to clear all the areas thus the need to formulate a management strategy that supports local people who are willing to clear the plant on their properties. Given that controlling IAPS is costly and labor intensive, developing a model that supports local clearing initiatives is likely to cut the WfW costs through travel budgets to the clearing sites. Biocontrol for *L. camara* in South Africa's inland regions has been reported to be less effective (Simelane, Katembo, and Mawela 2021), thus other initiatives, such as supporting clearing by local villagers need to be considered. Such support to local villagers could be in the form of cutting equipment, such as axes and chain saws, brochures with detailed information on how to properly cut or remove the plant, and chemicals for spraying the cut stumps.

Vegetation surveys at the household yard level revealed that *L. camara* is present in most properties. Although we recorded few abundances (averaging 2–3 plants per household yard), it is possible that household clearing that was mentioned by respondents is reducing *L. camara* abundances. However, of concern is that future distribution models predict that the plant will expand in Limpopo (Vardien et al. 2012), and given *L. camara's* invasion aggressiveness it is possible that the plant will proliferate on household yards in the future. Besides that, the high rainfall received in this area creates favorable conditions for *L. camara* to grow and expand on these properties (Vardien et al. 2012). In addition, *L. camara* tends to thrive in disturbed areas (Vardien et al. 2012), and household yards are highly disturbed. For example, most households in the study area practice home gardening (Semenya and Maroyi 2020) and clear land for construction, therefore, there exists a huge opportunity for *L. camara* to take advantage of the local household disturbance to spread.

Although our regression analysis had shortfalls, i.e., using purposively sampled household social data which is not a representation of the entire community, our regression model results are explanatory and offer the potential to explain the observed respondent patterns. Using the regression model results, *L. camara* abundance and increase was widely observed by social grant holders and respondents who perceive it to be commonly occurring and beneficial. Indeed, a previous study (e.g., Shackleton et al. 2019b) highlighted that IAPS with high occurrences and are beneficial to communities tend to shape people's perceptions. However, it was the young and those dependent on social grants who observed *L. camara* abundance and cover increase at household and area levels. This could be because the young and poor members of the community who depend on social grants are the most common users of *L. camara*, thus the tendency to notice its abundance and occurrence. Indeed, some studies (e.g., Ngorima and Shackleton 2019; Reynolds et al. 2020) have reported that poor members of the community are dependent on natural resources including IAPS. Our result contradicts the notion that older people (in this case pensioners) who are perceived to have stayed in an area for a long time tend to notice IAPS occurrence changes. For example, Jevon and Shackleton (2015) reported that only older people in Mazeppa Bay, Eastern Cape Province of South Africa could relate to the introduction and expansion of *L. camara* in the area as compared to the younger population and those who are new in the area. Overall, our regression model showed that the selected social factors hardly explained *L. camara* ecological data. Although this result cannot be generalized both at the species and landscape level, this could be because most respondents dislike *L. camara* and hardly see its benefits, therefore they hardly pay attention to the plant.

Conclusion

Despite its abundance in household yards and in the area, most of the respondents were not benefiting from the plant. Most respondents did not know that *L. camara* is an IAPS and this indicates that education and awareness campaigns on IAPS may play a role in helping communities navigate the tradeoffs between managing invasive versus native plants and to successfully implement an effective invasive species management plan. It is possible that knowledge and perceptions on *L. camara* in these villages are shaped by the plant's invasion history and extent in the area rather than its benefits since few benefits were mentioned. Local people are taking the initiative to control the plant in household yards, but they need financial support, information on plant management, and tools to enhance their current control initiatives. Local initiatives to manage *L. camara* at the household level need to be supported and incorporated into the national and regional plans to manage IAPS. Supporting current community and individual clearing initiatives could substantially reduce *L. camara* invasion extent as well as reduce clearing costs by management agencies since they will no longer need to contract people to clear the plant. Education and awareness campaigns on IAPS are important if the management of IAPS by local communities is to yield positive results. Local people possess important indigenous knowledge that can be used to manage IAPS, therefore clearing programme, such as WfW should tap into this knowledge to develop effective community-based alien plant control plans.

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Data Availability Statement

The data that support our research findings are available from the corresponding author on request.

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