Received: 11 May 2023 | Revised: 9 November 2023 | Accepted: 17 November 2023
DOI: 10.1111/csp2.13063

CONTRIBUTED PAPER

Conservation Science and Practice
A Journal of the Society for Conservation Biology
Open Access
WILEY

Venomous snakebites: Exploring social barriers and opportunities for the adoption of prevention measures

Harrison Carter[1,2,3] | **Xavier Glaudas**[4,5] | **Romulus Whitaker**[6] | **Gnaneswar Chandrasekharun**[6] | **Kimberley Hockings**[1] | **Ana Nuno**[1,7]

[1]Centre for Ecology and Conservation, Faculty of Environment, Science and Economy, University of Exeter, Cornwall, UK
[2]Wildlife Conservation Research Unit (WildCRU), Department of Biology, University of Oxford, Oxford, UK
[3]Interdisciplinary Centre for Conservation Science, Department of Biology, University of Oxford, Oxford, UK
[4]Departamento de Ecologia, Instituto de Biociências, Universidade de São Paulo, São Paulo, Brazil
[5]University of the Witwatersrand Johannesburg School of Animal Plant and Environmental Sciences, Johannesburg, South Africa
[6]Madras Crocodile Bank Trust, Centre for Herpetology, Mahabalipuram, Tamil Nadu, India
[7]Interdisciplinary Centre of Social Sciences (CICS.NOVA), School of Social Sciences and Humanities (NOVA FCSH), NOVA University Lisbon, Lisboa, Portugal

Correspondence
Harrison Carter and Kimberley Hockings, Centre for Ecology and Conservation, Faculty of Environment, Science and Economy, University of Exeter, Penryn, Cornwall TR10 9FE, UK.
Email: h.b.carter@exeter.ac.uk and k.hockings@exeter.ac.uk

Funding information
European Union's Horizon 2020 research and innovation programme, Grant/Award Number: 843865; University of Exeter

Abstract

Negative interactions between humans and venomous snakes are increasing, with the World Health Organization committed to halving snakebite deaths and disabilities by 2030. Evidence-based strategies are thus urgently required to reduce snakebite events in high-risk areas, while promoting snake conservation. Understanding the factors that drive the adoption of snakebite prevention measures is critical for the effective implementation of snakebite management strategies. We conducted in-person questionnaires ($n = 535$ respondents) with rural agricultural communities within the Thiruvarur District of Tamil Nadu, India, a national snakebite hotspot. Using a health belief model framework, we explored current snakebite prevention measures and factors impacting their adoption. The majority of respondents reported using multiple snakebite prevention measures. Perceived self-efficacy and perceived risk frequency of snakebites were important overall predictors of future adoption, whereas education, gender, relative wealth, and current adoption were important for specific measures. Achieving international commitments to support human–snake coexistence will require collective and collaborative action (e.g., governments, donor agencies, civil society organizations, researchers, and communities) underpinned by behavioural insights and context-specific solutions.

Kimberley Hockings and Ana Nuno contributed to this work equally and have agreed to share the last authorship.

KEYWORDS
coexistence, disease prevention, health belief model, human–wildlife conflict, snakebites, wildlife management

1 | INTRODUCTION

Negative interactions between humans and wildlife, such as overlap in resource use or aggressive encounters, represent one of the most significant and widespread issues facing human–wildlife coexistence (Madden & McQuinn, 2014). Negative interactions can drive resentment toward wildlife and conflict between people over how to deal with problematic wildlife behaviors, fueling retaliatory killings (Dickman et al., 2014). While negative interactions between large-bodied carnivores and people dominate coexistence literature (Su et al., 2022), venomous snakes (i.e., members of the Viperidae and Elapidae families) kill more humans than any other vertebrate animal (Small, 2021). Approximately 140,000 human lives are lost each year to venomous snakebites, and a further 400,000 are left with permanent disability (World Health Organization [WHO], 2019). The true mortality count remains unknown, masked by the nature of self-reporting in low-income communities (Harrison et al., 2009), where indirect socioeconomic costs for snakebite victims are rarely considered (Kularatne et al., 2014). Unknown is also the number of snakes killed by humans each year, which is long feared to far outweigh human fatalities (Whitaker & Shine, 2000). Across the tropics, snakes are regularly killed on sight by neighboring communities (Jadhav et al., 2018; Wood et al., 2022), which critically threatens their provision of ecosystem services in many tropical landscapes (Budnukaeku et al., 2021). A deeper understanding of these negative interactions is urgently required to develop solutions for snake conservation and promote sustainable coexistence with humans.

Snakebite events pose a significant challenge to human–snake coexistence. A range of anthropic (Mise et al., 2016; see Table S1 for a compilation of social factors influencing human–snake interactions) and environmental factors underpin negative interactions (Zacarias & Loyola, 2019). For example, while the abundance of individual venomous snakes does not differ significantly between tropical and temperate snake communities (Luiselli et al., 2020), snakebite events are asymmetrically prevalent across rural agricultural communities in tropical climates (Samuel et al., 2020). Field workers are particularly likely to suffer a venomous bite on the feet or hands (Harris et al., 2010; Singh et al., 2015). Bites are also observed at home in areas of low light or at night, where snakes are attracted by the smell of rodents and shelter from hot or rainy environmental conditions (Jayawardana et al., 2020). Fear of a fatal bite often instills negative attitudes and brutal killings of snakes across tropical zones (Alves et al., 2014; Jadhav et al., 2018; Onyishi et al., 2021). While community tolerance is lower toward venomous species (Kontsiotis et al., 2022), fear and the absence of knowledge required to identify harmless species often results in the killing of all sighted snakes (Balakrishnan, 2010; Wojnowski, 2010). This is concerning given the very act of killing snakes can elevate the human risk of envenomation and remove the provision of otherwise valuable ecosystem services (Pandey et al., 2016).

Snakes play an important role in the provision of ecosystem services. Pest control is perhaps their most valuable regulating service, with the potential to enhance crop yield for agricultural communities and reduce the risk of epidemic plagues through predation of rodents (Kontsiotis et al., 2022). Seed dispersal and their role as ecological indicators for climate variation are also valuable (Beaupre & Douglas, 2009; Reiserer et al., 2018). However, cultural services provided by snakes are observed to play the most important role in more harmonious coexistence (Narayanan & Bindumadhav, 2019; Pinheiro et al., 2016). For example, snakes frequent Hindu and Buddhist imagery across the tropics, influencing some communities to protect and even provide food for certain visiting species on account of their religious value (Allocco, 2013; Narayanan & Bindumadhav, 2019). While positive attitudes toward snakes and their conservation have been recorded in bite-risk areas, conflict management is still required to reduce snakebite events and generate capacity for snake conservation (Chowdhury et al., 2021).

In 2019, the WHO pledged to halve snakebite deaths and related injuries by 2030 (WHO, 2019). One challenge to achieving this goal is limited research exploring the current use and effectiveness of proposed snakebite management, irrespective of barriers to implementation (Malhotra et al., 2021; Wood et al., 2022). Snakebite management can be divided into two broad categories: medical treatment (e.g., antivenom) and technical prevention. To date, scientific research and funding have focused on the development of antivenom treatment for snakebite severity (Bulfone et al., 2018). However, financial cost, variable efficacy, and limited ability to deliver rapid treatment to rural communities where bites often occur have

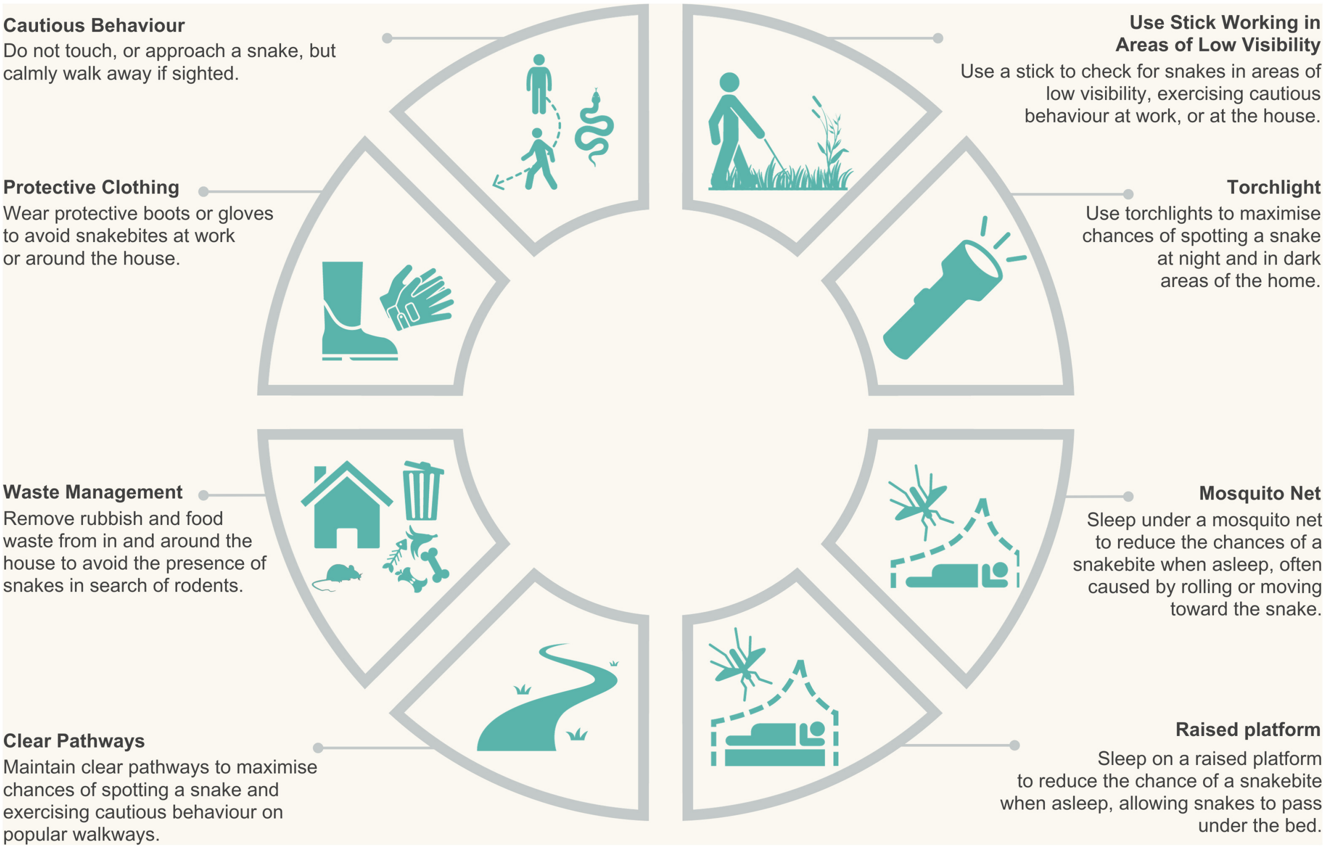

FIGURE 1 Visual representation of notable snakebite prevention measures as recommended by literature, local nongovernment organizations, and the Indian Government Ministry (MCBT, 2022; Ministry of Health & Family Welfare Government of India, 2016; Williams et al., 2019).

caused many to question its applied impact in tropical countries (Alangode et al., 2020; Habib & Brown, 2018; Laxme et al., 2019).

A range of "recognized prevention measures" have been recommended by scholars, nongovernment organizations, and governments to prevent snakebite events, including the use of protective boots or gloves for fieldwork, mosquito nets, raised platforms for sleeping at home, and torches to limit surprise encounters with snakes, particularly at night (Ministry of Health & Family Welfare Government of India, 2016; Rodrigo et al., 2017; WHO, 2019). Other recommendations include vigilant behavior when working or walking in the fields, maintaining wide field paths, removal of waste around the home, controlling rodents in and around households, and filling holes in house walls where snakes can easily enter (Figure 1; Williams et al., 2019; Madras Crocodile Bank Trust [MCBT], 2022). However, with snakebite mortality consistently high year on year, few studies have explored affected communities' willingness to adopt prevention measures to inform snakebite prevention efficacy (Malhotra et al., 2021). For example, physical discomfort and deep-rooted cultural beliefs can reduce the adoption of protective clothing by at-risk communities (Ayode et al., 2013; D'Août et al., 2009), and financial limitations limit the scalability of other purchased prevention products (Wood et al., 2022). To reduce snakebites and facilitate snake conservation, it is crucially important to understand the drivers of effective snakebite prevention.

Effective snakebite prevention planning would benefit from pre-emptively considering what solutions might be more widely accepted and effective, suitably accounting for and responding to future human behavior (Carter et al., 2020; Travers et al., 2019). A range of social factors, including perceptions of threat, effectiveness, ease of use, and maintenance requirements, are suggested to drive the adoption of preventative measures within the wider coexistence literature (Denninger Snyder & Rentsch, 2020; Noga et al., 2015). However, integrated frameworks from social science are seldom employed to explore the presence of such factors (Nuno et al., 2022). The health belief model (HBM) is one of the most frequently cited public health frameworks for understanding human behavior when faced with a threat to health (Jones et al., 2014) (Figure S1). HBM

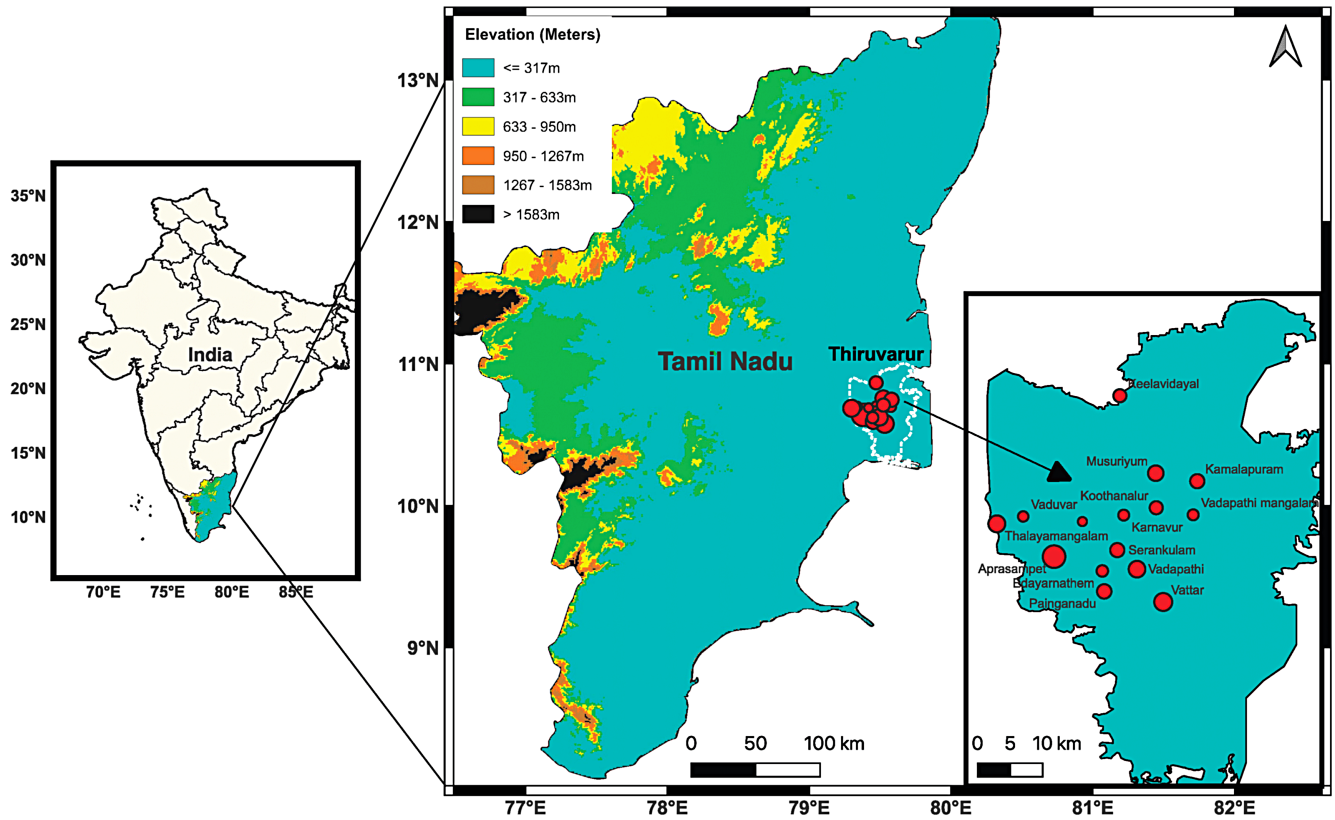

FIGURE 2 Map of study sites ($n = 15$ red dots) within the Thiruvarur District of Tamil Nadu State, India. The dot size reflects the relative sample size per study site (range = 25–75 participants).

proposes that perceptions of threat are in part driven by perceived severity of impact, perceived risk of contagion, and cues to action (e.g., reminder notifications). Alongside threat perceptions, the perceived benefits of treatment combined with perceived barriers to access and self-efficacy contribute toward adoption likelihood, underpinned by an individual's sociodemographic background. While HBM continues to be extensively used in health literature (Al-Sabbagh et al., 2022; Walrave et al., 2020; Wong et al., 2021), the application within coexistence literature is limited (Nuno et al., 2022) and has never been applied to explore the adoption of snakebite prevention measures.

Focusing on rural agricultural communities in Tamil Nadu, India—the country where approximately 40% of snakebite deaths worldwide occur (Suraweera et al., 2020)—this study aimed to identify key factors related to individuals' current and potential future adoption of snakebite prevention measures. We addressed the following research questions: (1) What measures are currently adopted to prevent snakebites? (2) What drives potential future adoption of snakebite prevention measures? (3) What barriers hinder the future adoption of snakebite prevention measures? Ultimately, we aim to contribute toward the improved uptake and efficacy of snakebite preventive measures to reduce snakebites, promoting snake conservation and progressively harmonious coexistence.

2 | METHODS

2.1 | Study site

We conducted this study in the Thiruvarur District of Tamil Nadu in southern India (Figure 2). Tamil Nadu is one of the highest populated states in India (approximately 72 million people), and around half of the population resides in rural areas (Government of Tamil Nadu, 2017). Furthermore, more than 70% of the total workforce in the Thiruvarur District depends upon agriculture for livelihood purposes, where paddy is the main crop (Paramasivan & Pasupathi, 2016). The area comprises multiple ethnic groups, with most people practicing Hinduism (Waring, 2012). Poverty is prevalent in rural communities in part owing to limited agricultural development (World Bank Group, 2017). Around 6%–10% of Thiruvarur's population live in absolute poverty, with annual per capita income amounting to 27,408 INR (299 GBP) (Government of Tamil Nadu, 2017).

Tamil Nadu has frequently been identified as a high snakebite risk state in southern India (Salve et al., 2020; Suraweera et al., 2020). Representing just 5% of India's population, Tamil Nadu has been estimated to contribute around 20% of the official national snakebite mortality cases (Samuel et al., 2020). This has been suggested to be a product of high agricultural reliance, a rural population living in poverty, and a high abundance of India's four medically significant venomous snakes (Samuel et al., 2020); the spectacled cobra (*Naja naja*), the Russell's viper (*Daboia russelii*), the saw-scaled viper (*Echis carinatus*), and the common krait (*Bungarus caeruleus*) (Whitaker & Whitaker, 2012). Bites are most likely to occur at lower altitudes, specifically less than 500 m above sea level, in correlation with rainfall and crop harvesting (April–June and September–October) (Suraweera et al., 2020; Vaiyapuri et al., 2013). The four medically significant species are terrestrial but vary in nocturnal and diurnal activity patterns, causing a consistent risk for agricultural workers (Whitaker & Whitaker, 2012). While currently listed as "least concern" on the IUCN's Red List (IUCN, 2022) and protected under The Wildlife Protection Act (1972) of India, conflict with humans and land use change threaten these species' persistence in India (Janani et al., 2016). This is especially true for wet agricultural environments, which, in comparison to forested areas, are thought to provide a preferable habitat for medical species such as *D. russelii* and *N. naja* that heightens the potential for negative interactions with local farmers (Whitaker & Martin, 2015). These species not only provide crucial ecosystem services such as seed dispersal and pest control in Tamil Nadu, but hold deep cultural value for neighboring communities (Narayanan & Bindumadhav, 2019). In particular, the Indian cobra (*N. naja*) is generally worshiped in southern India and is often pictured in Hindu imagery (Lange, 2019). It is believed that worshiping *N. naja* can enhance fertility for women, where women are reported to bring milk or eggs as offerings to the local temple for prayer (Allocco, 2013). However, it is believed that killing or otherwise disturbing a mating pair of snakes can place a curse on the family, limiting fertility and otherwise causing marital harm (Allocco, 2013). While *N. naja* appears to carry cultural values that support coexistence, either through fear or hope, other species may be perceived differently. For example, fear also drives the killing of many snakes in the region, especially snakes identified as venomous that carry a higher perceived risk to human life (Landry Yuan et al., 2020). Russell's vipers (*D. russelii*) are generally more feared, and many other species carry harmful myths about them, but with less cultural/religious value compared to *N. naja* are more likely to be killed. Effective conflict management is urgently needed to reduce snakebite events and support valuable coexistence for snake species overall, despite observed tolerance toward the *N. naja* (Chowdhury et al., 2021).

2.2 | Survey design and administration

We used an in-person questionnaire combining closed- and open-ended questions to gather information on the current and potential future adoption of snakebite prevention measures in rural agricultural communities. We designed our questionnaire using the HBM framework and incorporated feedback from local partners to ensure relevance. Combining questions on demographic characteristics (age, gender, education, and relative wealth), current adoption of snakebite prevention measures, sense of responsibility, perceived effectiveness of measures alongside perceived self-efficacy, and perceived susceptibility and severity of snakebite (Table 1), we investigated which factors potentially affect adoption of recognized snakebite prevention to inform the design of conservation initiatives in situ. A standardized list of 12 recognized snakebite prevention measures was provided to each participant to explore underpinning drivers of future adoption across each measure (see Appendix SI), where open-ended questions were used to understand current snakebite prevention behavior; previous knowledge of these prevention measures was not assessed. We also assessed perceived barriers to the adoption of snakebite prevention measures and explored individual perceptions of snakes and snakebite (disgust, pest control capability, cultural existence value, fear, and protection through worship) (Fortin et al., 2020; Narayanan & Bindumadhav, 2019; Rádlová et al., 2019). After survey development, we ran a pilot study with 47 people from a local rural community excluded from the final survey. Their responses helped determine the average completion time and ensure the questions were easily understandable. Throughout the study, we used the term snakebite to refer to the interaction between venomous snakes and humans as opposed to snakebites on livestock or other animals that may have indirect impacts on human livelihoods. A copy of both English and Tamil versions of the final questionnaire is available in Appendices SI and SII.

To administer the questionnaire, the MCBT helped to identify 15 agricultural communities within the Thiruvarur District willing to engage in research, where environmental characteristics were

TABLE 1 Variables used to explore sociodemographic differences in both current adoption of snakebite prevention, and potential drivers of respondents' self-reported willingness to adopt key snakebite prevention measures.

HBM framework component	Indicator/variable	Data type	Description
Dependent variables			
Potential future adoption of specific snakebite prevention measures		Ordinal	For each specific snakebite prevention measure, self-reported willingness to adopt it during daily life on a 5-point Likert-type item (from "*not at all willing*" to "*very willing*").
Independent variables: Demographics			
Sociodemographic factors	Age	Categorical	Age group of the respondent (six-level factor: 18–24; 25–34; 35–44; 45–54; 55–64; 65+).
	Gender	Binary	Gender of the respondent (male and female).
	Education level	Categorical	Respondent's reported level of education (four-level factor: no formal education, primary education, secondary education, post-school education).
	Relative wealth	Binary	Whether material style of life is below or equal to median (estimated from principal component score based on household assets used by Indian census, including pressure cooker (1/0); colored television (1/0); refrigerator (1/0); table (1/0); washing machine (1/0); sewing machine (1/0); air conditioning (1/0); mattress (1/0); scooter/motorbike (1/0); toilet (in-house) (1/0); concrete roof (1/0).
Independent variables: Perceptions of snakebite and prevention measures			
Current adoption of snakebite prevention measures		Binary	Whether someone currently takes measures to prevent snakebites ("adopter") or not ("potential new adopter"). (This variable was subsequently used as an independent variable to explore variation in potential adoption).
Perceived susceptibility and severity of snakebite	Perceived frequency of snakebites	Ordinal	Level of perceived frequency of snakebite events reported on a 5-point Likert-type item (from "*very rare*" to "*very often*").
	Perceived consequences from snakebite	Ordinal	Level of agreement with five separate statements related to consequences of snakebite: mortality, physical damage, psychological damage, and job opportunities. Based on 5-point Likert-type items (from "*strongly disagree*" to "*strongly agree*").
Perceived effectiveness		Continuous	Level of perceived effectiveness of each specific measure in preventing snakebites. Based on 5-point Likert-type items (from "*not effective all*" to "*very effective*").
Perceived self-efficacy		Continuous	Level of perceived confidence in using each specific measure in preventing snakebites. Based on 5-point Likert-type items (from "*not confident at all*" to "*very confident*").
Sense of responsibility		Binary	Whether option "individual" was selected as someone responsible for enforcing the use of snakebite prevention measures.

Abbreviation: HBM, Health Belief Model.

representative of Tamil Nadu's snakebite risk. To reach a wide range of participants within these communities, we conducted in-person questionnaires between May and June 2022, opportunistically approaching people working in agricultural areas, homesteads, or village communal areas. To capture enough intra-community variation, we aimed to interview at least 25 participants per community. While the likelihood of self-selection bias of opportunistic sampling limits reliably broad extrapolation (Robinson, 2014), results can highlight issues worthy of further exploration. Questionnaires took around 20 min to complete, and we collected data on iPads using an offline version of Qualtrics data collection software. Three Indian research assistants, who received comprehensive in-situ training before data collection, carried out questionnaires in local Tamil. For open-ended questions, we audio-recorded participant responses for later translation from Tamil to English and transcription for analysis. During an introductory statement, we informed participants about the purpose of the project, the voluntary nature of their participation (including audio recording), the anonymity of data shared, and the right to terminate the questionnaire at any time. Data collection was approved by the Ethics Committee at the University of Exeter (Approval ID: 513153).

2.3 | Data analysis

We used ordinal logistic regressions to explore relationships between the potential adoption of specific prevention measures (participants' self-reported willingness to adopt future snakebite prevention measures: not willing; a little willing; neutral; somewhat willing; extremely willing) and potential predictors without making assumptions about interval distance or distribution. We used the Akaike information criterion (AIC) as a means of model selection, displaying and ranking all possible model combinations of log-likelihood while penalizing for the number of parameters (Wagenmakers & Farrell, 2004). Final models were calculated as an average across models with AIC <4 using the MuMIn package v.1.42.1 (Barton, 2018); AIC ≥4 reflecting substantially less model support (Anderson & Burnham, 2002). The relative importance of predictor variables has been expressed as the sum of Akaike weights for variables present in the final averaged models. Uninformative parameters were identified using an 85% confidence interval to avoid the removal of variables in best-performing models supported by lower AIC values (Arnold, 2010). We conducted all statistical analyses using R version 7.1.554 (RStudio Team, 2022).

To explore the potential future adoption of snakebite prevention measures, we included all relevant sociodemographic (i.e., age, gender, education, and relative wealth) and perception variables (i.e., sense of responsibility, perceived effectiveness, perceived self-efficacy and perceived susceptibility, and severity of snakebite) alongside current adoption of snakebite prevention measures together in the statistical models. We applied this approach separately for each key target prevention measure (sleep on a raised platform, wear protective clothing on dry ground, and use a stick to check for snakes in areas of low visibility). These three behaviors reflected the lowest potential adoption levels (see Section 3) and were deemed to represent measures that may be affected by different drivers or unpredictable barrier types. Wearing protective clothing on the wet ground was excluded from further analysis on account of the invariability of barriers facing adoption, where it became clear wet ground conditions directly blocked adoption.

For open-ended questions (i.e., free-listing prevention measures currently adopted and perceived barriers), we subsequently categorized transcript data; inductively compared thematic codes and ultimately grouped them into overarching themes in line with the exploratory nature of the study (Table S2; Terry et al., 2017).

3 | RESULTS

A total of 535 people took our survey across the 15 rural agricultural communities (range = 25–75 participants per community) from the district of Thiruvarur in Tamil Nadu (Table S3). Considering individual snake perceptions, while participants generally acknowledged a fear of snakes, these species were perceived to hold ecosystem service value in the form of pest control (Figure S2). Participants were more divided when considering feelings of disgust toward snakes, their cultural existence value, and the perceived effectiveness of worship as a form of snakebite prevention. Snakebites themselves were generally considered to be rare or very rare. Despite this rarity, participants acknowledged the high impact of bite incidents on physical health, psychological health, future job opportunities, family care burden, and human life (Figure S3). Among the surveyed participants, 371 (69%) reported already adopting snakebite prevention methods in their daily lives (hereby referred to as "adopters"). The remaining 164 survey participants (31% of respondents) refrained from snakebite prevention altogether (hereby referred to as "non-adopters"), although 46% felt they should on reflection. Specific sample sizes are reported throughout the results as sections vary according to participants' experiences.

3.1 | What measures are currently adopted to prevent snakebites?

Among the 371 current adopters, 217 (59%) exclusively used snakebite prevention measures commonly recognized in the literature (Figure 1). The remaining 41% either exclusively used measures unrecognized in literature (38%) or a mixture of both recognized and unrecognized methods (62%). Overall, the median number of measures used per participant was two (IQ range = 0–5), with 74% of measures adopted exclusively at or around participant homes.

When exploring specific measures adopted to prevent snakebites, the intentional maintenance of clean floors inside homes (clearing of cooking equipment and possessions) and tidy backyards (clearing of debris and vegetation) were the two most commonly recognized snakebite prevention measures reported (Figure 3); accounting for 22% and 19% of all measures, respectively. Other recognized snakebite prevention measures were also reportedly adopted, including the use of a torch at night (7%), covering holes in the house (floor or wall) through which a snake could enter (6%), and cautious behavior walking and working (6%). However, unrecognized snakebite prevention measures accounted for 25% of all responses. The most popular of which include the spreading of salt around the four corners of the home (25%), spraying or spreading turmeric and garlic (25%), and the wearing of chappals (sandals) around the home or field (9%). Other unrecognized measures reported include spreading cow dung around the home (6%), fencing the property (5%), and spraying

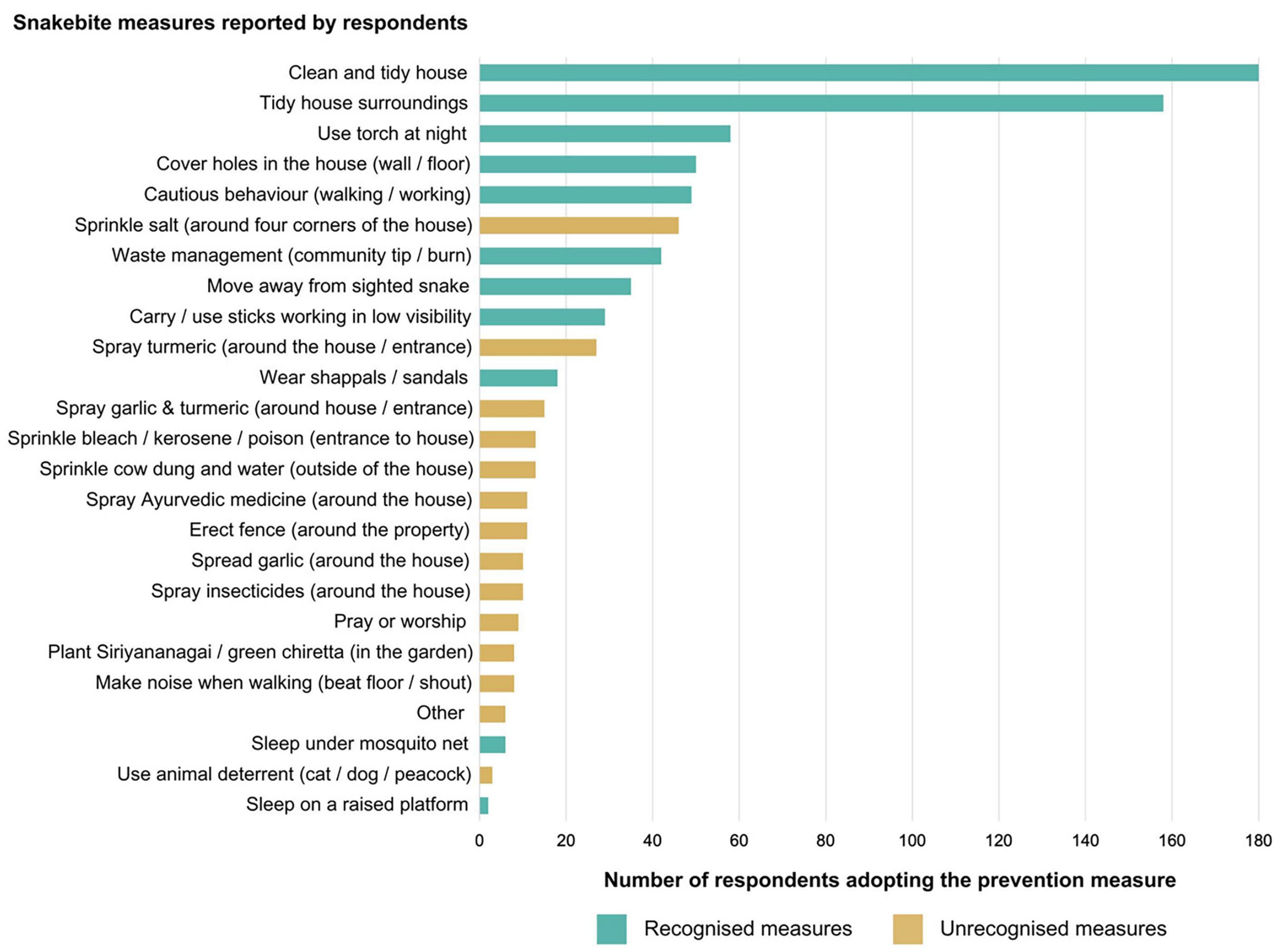

FIGURE 3 Types of snakebite prevention measures currently adopted within the Thiruvarur District and the number of participants mentioning each type of concern. Recognized measures (shown by blue bars) refer to those reported by the WHO, Indian Ministry of Health and Family Welfare alongside local conservationists and snakebite literature, whereas unrecognized measures (shown by orange bars) refer to other approaches unreported from such sources.

TABLE 2 Parameter unconditional estimates obtained from the averaged ordered logistic regressions fitted to respondents' answers obtained using Likert-type scales to assess self-reported willingness to adopt specific snakebite prevention measures in day-to-day life.

	Sleep on a raised platform			Wear protective clothing on dry ground (boots, gloves, etc.)			Use a stick to check for snakes in areas of low visibility		
Parameter	**Est (SE)**	***z* Value**	**RVI**	**Est (SE)**	***z* Value**	**RVI**	**Est (SE)**	***z* Value**	**RVI**
(a) Independent variables: Demographics and type of adopter									
Type of adopter			0.02			<0.01			**0.29**
Non-adopter	−0.02 (0.12)	0.19		0.00 (0.05)	0.06		−0.49 (0.5)	0.98	
Age	–	–	–			<0.01	–	–	–
25–34				−0.01 (0.13)	0.11				
35–44				−0.02 (0.17)	0.12				
45–54				−0.01 (0.13)	0.11				
55–64				−0.01 (0.09)	0.07				
64+				−0.01 (0.12)	0.1				
Gender			**0.39**			**0.26**			0.19
Male	−0.77 (0.25)	3.09		−0.24 (0.28)	0.83		−0.13 (0.25)	0.53	
Education			0.02			0.14			0.04
Primary education	0.02 (0.14)	0.18		−0.02 (0.24)	0.1		0.05 (0.21)	0.25	
Secondary education	0.03 (0.18)	0.19		−0.10 (0.28)	0.36		0.06 (0.22)	0.25	
Post-school education	0.01 (0.12)	0.08		0.19 (0.40)	0.47		0.09 (0.32)	0.27	
Relative wealth	0.42 (0.15)	2.74	**0.39**	0.00 (0.07)	0.04	0.08	−0.01 (0.08)	0.17	0.09
(b) Independent variables: Social norms and perceptions									
Sense of responsibility			0.11			0.09			0.19
No	−0.08 (0.2)	0.38		0.02 (0.14)	0.15		0.18 (0.33)	0.55	
Perceived effectiveness	−0.00 (0.04)	0.04	0.05	0.04 (0.1)	0.45	0.14	0.04 (0.1)	0.42	0.14
Perceived self-efficacy	0.81 (0.08)	10.03	**0.39**	0.62 (0.07)	8.21	**0.46**	1.16 (0.13)	9.12	**0.49**
Snakebite risk (frequency)			0.08			0.03			0.04
Rare	−0.12 (0.27)	0.44		−0.01 (0.09)	0.16		−0.04 (0.17)	0.25	
Moderate	−0.13 (0.33)	0.39		−0.04 (0.18)	0.2		−0.07 (0.28)	0.25	
Often	−0.19 (0.47)	0.41		−0.04 (0.20)	0.17		0.04 (0.30)	0.14	
Very often	2.23 (4.5)	0.50		0.84 (3.43)	0.25		0.9 (3.04)	0.29	
Snakebite severity (death)			0.02			0.02	–	–	–
Disagree	0.00 (0.17)	0.02		0.01 (0.16)	0.01				

(Continues)

TABLE 2 (Continued)

Parameter	Sleep on a raised platform			Wear protective clothing on dry ground (boots, gloves, etc.)			Use a stick to check for snakes in areas of low visibility		
	Est (SE)	z Value	RVI	Est (SE)	z Value	RVI	Est (SE)	z Value	RVI
Neither disagree or agree	0.03 (0.20)	0.16		−0.00 (0.1)	0.02				
Agree	0.02 (0.19)	0.12		−0.00 (0.11)	0.07				
Strongly agree	0.05 (0.24)	0.24		0.00 (0.09)	0.00				
Snakebite severity (psychological injury)			**0.25**	–	–	–	–	–	–
Disagree	−0.91 (0.94)	0.97							
Neither disagree or agree	−0.54 (0.73)	0.73							
Agree	−0.91 (0.85)	1.07							
Strongly agree	−1.26 (1.08)	1.17							
Snakebite severity (future work opportunity)			**0.31**	–	–	–			<0.01
Disagree	0.89 (0.81)	1.01					0.01 (0.13)	0.09	
Neither disagree or agree	1.59 (1.26)	1.26					−0.01 (0.21)	0.03	
Agree	1.47 (0.93)	1.57					0.03 (0.22)	0.15	
Strongly agree	1.65 (1.08)	1.54					0.02 (0.17)	0.14	
Snakebite severity (physical injury)	–	–	–	–	–	–			**0.49**
Disagree							−1.1 (0.81)	1.36	
Neither disagree or agree							−1.35 (0.93)	1.44	
Agree							−1.57 (0.72)	2.17	
Strongly agree							−0.42 (0.69)	0.61	

Note: Reference levels: adopter; 18–24 years old; female; no formal education; sense of responsibility; snakebite risk (frequency) very rare; snakebite risk (house day) low; snakebite risk (house night) low; snakebite risk (field day) low; snakebite risk (field night) low; snakebite severity (death) strongly disagree; snakebite severity (psychological injury) strongly disagree; snakebite severity (future work opportunity) strongly disagree; snakebite severity (physical injury) strongly disagree. Numbers in bold indicate relative variable importance ≥25%. Shading denotes 85% confidence intervals that do not overlap zero. – Denotes absence from the best-performing models.

Conservation Science and Practice
A Journal of the Society for Conservation Biology
Open Access
WILEY

TABLE 3 Key perceived barriers to adopting recognized snakebite prevention measures (number of participants mentioning each type of concern is reported below); overarching themes ($n = 6$) and subgroups ($n = 34$) with supporting quotes.

Theme	Groups	Supporting quotes
Practicality (n = 306)	Difficulties of wearing boots in wet ground conditions ($n = 206$)	"In the wet area if we wear shoes then mud and water will enter into the shoes. We cannot work by wearing this…we can wear shoes in the dry area" [Adopter, Female, Agricultural worker].
	Opportunity cost (time/burden) of using products (boots/stick/gloves) ($n = 28$)	"If we wear shoes then we cannot do work quickly. If we work slowly then our owner will not call us for the next time. So, we think that anything can bite us, but we need to have job for tomorrow and because of this we won't wear shoes" [Adopter, Male, Agricultural worker].
	Ease of sleeping on the floor ($n = 11$)	"Only pillow is needed to sleep on the floor" [Non-adopter, Male, "Other" occupation].
	Maintenance requirements of products (boots/torch/raised bed) ($n = 8$)	"If we are working on wet lands, the shoes will get damaged. How long will you keep changing it?" [Adopter, Female, Agricultural worker].
	Situational use of prevention products ($n = 8$)	"While at home, we will clean the floor and sleep there. While in the fields we will have cots and sleep on it" [Adopter, Female, Agricultural worker].
	Boot damage to crops ($n = 7$)	"If we wear shoes and work, the crops will not grow properly" [Adopter, Male, Agricultural worker].
	Forgetting to use prevention products (torch/boot/stick) ($n = 6$)	"When we go out without torchlight in the dark, then we cannot do anything. Sometimes I forget to take it with me" [Adopter, Male, Agricultural worker].
	Raised platform not fit for collaborative family sleeping ($n = 5$)	"Cot is small. I have to make the kids sleep next to me…so floor is better" [Adopter, Female, Agricultural worker].
	Impracticality of wearing gloves in wet ground conditions ($n = 4$)	"We cannot work properly. We cannot balance properly if we wear gloves and pick up equipment's" [Non-adopter, Male, Agricultural worker].
Financial ($n = 148$)	Limited financial budget for prevention products in general ($n = 46$)	"We all have financial issue…we don't have anything and that is why we are going to work" [Non-adopter, Female, Agricultural worker].
	Limited financial budget for boots ($n = 46$)	"We get some Rs. 600 per day… with that amount we cannot buy shoes" [Non-adopter, Female, Agricultural worker].
	Limited financial budget for a raised bed or home improvements ($n = 35$)	"I cannot afford the get a cot" [Non-adopter, Female, Agricultural worker].
	Deprioritisation of work equipment purchases ($n = 12$)	"People who have to buy it will think twice about the cost, they prefer to buy a 50/− slipper instead of a 200/− shoe for work" [Adopter, Male, "Other" occupation].
	Financial prioritization of day to day life expenditure ($n = 5$)	"I run the family with what little I get" [Adopter, Male, Agricultural worker].
	Limited financial budget for mosquito net ($n = 4$)	"We find it difficult to even buy a mosquito net" [Non-adopter, Female, Agricultural worker].
Familiarity ($n = 130$)	Wearing boots or shoes ($n = 79$)	"I am used to working without it. Since I was a child I used to go to the fields" [Adopter, Male, Agricultural worker].
	Familiarity with sleeping on the floor ($n = 24$)	"From birth, we have been sleeping on the floor only. I will sleep on the floor only" [Adopter, Male, Agricultural worker].
	Wearing protective clothing in general ($n = 14$)	"In this area people are not habituated with such kind of things (boots/gloves)" [Adopter, Male, Agricultural worker].
	Perception of footwear ($n = 13$)	"We wear chappals, but not shoes" [Adopter, Male, Agricultural worker].
Physical comfort ($n = 128$)	Comfortable to sleep on the floor ($n = 44$)	"After working hard I feel happy to sleep on the floor. If we sleep on the cot then we will have body pain" [Non-adopter, Female, Agricultural worker].

(Continues)

TABLE 3 (Continued)

Theme	Groups	Supporting quotes
	Uncomfortable wearing boots ($n = 42$)	"You can't be in shoes for a long time, you can wear it only for a short while, otherwise you will get pain" [Adopter, Male, Agricultural worker].
	Health benefits of sleeping on the ground ($n = 23$)	"That is like yoga. It is good if you sleep on the floor. Better than a bed" [Adopter, Female, Agricultural worker].
	Cooler to sleep on the floor ($n = 9$)	"Because of the heat, if we sleep on the floor, it will be cool" [Adopter, Female, Agricultural worker].
	Cannot sleep under mosquito nets ($n = 6$)	"You cannot sleep inside a mosquito net" [Adopter, Male, Agricultural worker].
	Uncomfortable to sleep on a raised bed/cot ($n = 4$)	"I have a cot. But I cannot sleep on the cot. If I lie on the floor, I sleep well" [Non-adopter, Male, "Other" occupation].
Social pressure ($n = 93$)	Concerns about community reaction to protective clothing ($n = 48$)	"They think that it is wrong to wear such things and so they won't allow us to wear shoes and gloves while working in the agriculture field" [Adopter, Male, Agricultural worker].
	Social embarrassment wearing protective clothing ($n = 18$)	"I am embarrassed to wear shoes while going to the farms, hence we cannot do it" [Adopter, Male, Agricultural worker].
	Concerns of employer reaction to protective clothing, including ($n = 12$)	"We think that we should not wear those things on the land. They scold us if we wear and so we won't wear it" [Adopter, Female, Agricultural worker].
	Concerns of being the first adopter ($n = 10$)	"If you are the only wearing it, then it is embarrassing, they will make fun of us. If everyone start wearing it, I can also do it" [Adopter, Female, Agricultural worker].
	Cast based estrangement from shoe wearing ($n = 5$)	"Those who go to the forest don't wear shoes. Those in the officer level only wear shoes" [Adopter, Male, Agricultural worker].
Cultural beliefs ($n = 73$)	Respect for agricultural land ($n = 59$)	"We consider the farming lands to be Godly, we don't wear shoes and slippers… out of respect we don't do it" [Adopter, Male, Agricultural worker].
	Identify with barefoot walking ($n = 8$)	"We cannot wear shoes, we just work barefooted. We do all work barefooted" [Adopter, Male, Agricultural worker].
	Uncourageous nature of prevention measures ($n = 6$)	"If I go alone then I won't carry any stick. I go without any fear" [Adopter, Female, Agricultural worker].

potentially dangerous chemicals (kerosene/bleach/animal poison) on the entrance to homes (6%). Variations of specific prevention measures adopted were not recorded across villages due to socioeconomic similarity and the consistent nature of snakebite risk.

3.2 | What drives potential future adoption of snakebite preventatives?

A total of 374 survey participants, including 262 adopters and 112 non-adopters, responded to additional questions about their future behavior regarding the adoption of snakebite prevention measures. The remaining 161 participants were unsure about their future snakebite prevention behavior and were excluded from subsequent analysis. A vast majority of 361 participants (97%) reported never having attended a snakebite awareness event before and were keen to utilize recognized snakebite preventatives in their day-to-day lives. This is reflected in participants' generally high willingness to adopt numerous recognized measures either in the field or at home (Figure S4). Over 96% of participants showed an extreme willingness to maintain wide field paths, dispose of waste away from their houses, store food off the ground, repair holes in their homes where snakes can easily enter, use a torch in low light, and employ cautious behavior when moving crops moving forward. These measures were considered to be very effective (Figure S5), and participants were generally very confident in their ability to use them in everyday life (Figure S6). In comparison, participants were less willing to wear protective clothing, especially in wet conditions, and reluctant to sleep on a raised platform or use a stick to cautiously check for snakes in areas of low visibility; 22%–68% of respondents expressed no or low willingness to comply with these recommendations. Factors affecting variation in these measures were explored further (apart from the use of protective clothing in wet ground conditions, where it was clear from participants that wet environmental conditions blocked willingness of future adoption).

Focusing on protective clothing worn in dry conditions (for which 23% of participants reported a no/low willingness to comply), gender and perceived self-efficacy were the most important variables to explain future adoption willingness, and both included parameters with model-averaged 85% confidence intervals (CIs) not crossing zero (Table 2). Men were less willing to adopt this measure than women, and people who perceived higher levels of self-efficacy of this measure were more willing to adopt it (Figure S7).

Further key variables were uncovered as important predictors for sleeping on a raised platform or using a stick to cautiously check for snakes in areas of low visibility with varying effects (Table 2; Figures S8 and S9). For example, above-average relative wealth was an important predictor of participants' willingness to sleep on a raised bed at night, where men were less willing to adopt this measure than women. Participants currently not adopting prevention measures were less willing to use sticks to check for snakes in low visibility moving forward, although this was not an important predictor of future use for other prevention measures. Considering the effect of perceived snakebite severity statements on future—psychological injury, physical injury, and opportunities for future work—were also important and informative, although their effects were not always conclusive. Critically, perceived self-efficacy was the only important predictor present across all three behaviors, unanimously reflecting a positive effect on adoption (Table 2; Figures S7–S9).

3.3 | What barriers threaten the future adoption of snakebite preventatives?

A total of 535 survey participants reported perceived difficulties when attempting to adopt the recognized prevention measures explored in this study. Identified barriers mostly related to (1) practicality (e.g., wearing clothing in wet conditions); (2) financial (e.g., cost of a bed and/or mosquito net); (3) unfamiliarity (e.g., wearing boots or protective clothing in general); (4) physical comfort (e.g., blisters in boots or poor sleep on a raised platform or under mosquito net); (5) social pressure (e.g., embarrassment or public scolding); (6) cultural beliefs (e.g., only walk barefoot on the land) (Table 3). Practicality was the most referenced barrier for future adoption ($n = 306$), although results were dominated by concerns relating to the impracticability of boots when farming in paddy fields and the resultant impact on working efficiency if adopted ($n = 206$). Financial hurdles ($n = 148$), familiarity ($n = 130$), and physical comfort ($n = 128$) of new measures to prevent snakebites were frequently raised, where the adoption of boots and a raised bed were the focus of concern. Social pressure ($n = 93$) and cultural beliefs ($n = 73$) were also seen as barriers to the future adoption of snakebite prevention measures, where the use of protective clothing (mainly boots) represented the majority of concerns. Agricultural fields were regarded by some as holy areas that should only be entered barefoot out of respect, where it was felt that social embarrassment or even scolding from employers would await members of the community who chose to wear protective clothing.

4 | DISCUSSION

Effective prevention of negative human–wildlife interactions should pre-emptively examine factors affecting the future adoption and effectiveness of mitigation measures, with consideration for both biodiversity and human livelihoods (Carter et al., 2020; Travers et al., 2019). Based on a district-wide sample of 535 respondents in 15 rural agricultural communities within the Indian state of Tamil Nadu, this study identified snakebite prevention measures currently employed, characterized adopters, and utilized the HBM to explore factors influencing potential future adoption.

Considering prevention measures employed at the time of the study, the vast majority of participants reported adopting multiple snakebite prevention measures, although many of these are not recognized by current literature. With a focus on potential future adoption, three key prevention measures were highlighted at the time of study to represent lower levels of willingness for potential future adoption: sleep on a raised platform, wear protective clothing on dry ground, and use a stick to check for snakes in areas of low visibility. These measures, protective clothing in particular, also produced the majority of issues raised by participants when describing their perceived barriers to adoption, including familiarity, practicality, and physical comfort, alongside cultural and social environmental conditions. Interestingly, a range of factors were informative predictors of future adoption, with just two variables highlighted as informative across all three (perceived self-efficacy and perceived risk frequency). These findings uncover key factors central to the future success of prevention measures, while drawing attention to their context-specific nature.

4.1 | Current snakebite prevention measures and their adopters

Current adopters report the use of both recognized and unrecognized measures to mitigate the risk of snakebites, which are most often used around the home. Frequently adopted recognized measures include cleaning the house to limit rodents that attract snakes, removing debris that snakes may use as cover from surrounding areas, and the use of torchlight to more easily spot snakes at night or in areas of low light within the home where snakes may take refuge from heat or rain. Use of these should be further encouraged, especially in the general tidiness of homes and garden areas, to reduce the presence of rodents that will otherwise attract all four medically significant snake species abundant within lowland agricultural communities of Tamil Nadu (Samuel et al., 2020). This may carry particular relevance to mitigate negative interactions with the Indian cobra (*N. naja*), which are a presumably diurnal species and more likely to actively hunt rodents at times when people may be more active around their home (Alirol et al., 2010). Torchlights, on the other hand, maybe more valuable to avoid negative interactions with predominantly nocturnal species such as Russell's viper (*D. russelii*), saw-scaled viper (*E. carinatus*), and common krait (*B. caeruleus*), which carry additional snakebite risk as their relatively small size could make them harder to spot in comparison with larger species (da Silva et al., 2019).

Prevention measures are found to be price-elastic purchases. While the relatively frequent adoption of torches observed in this study implies financial accessibility, relative wealth within low-income communities surveyed remained an important predictor of adoption and further reinforced the critical need for locally affordable solutions (Malhotra et al., 2021; Rodrigo et al., 2017; Samuel et al., 2020). Affordable solutions could take the form of free preventative behaviors, such as checking for snakes in areas of low visibility, where snakes can be easily stepped on or touched during busy harvest periods (Suraweera et al., 2020). Preventive behaviors can be extremely effective for inciting human–snake coexistence when grounded in cultural or religious contexts, for example, *N. naja* are often considered sacred in Hindu culture and communities have been observed to show high degrees of tolerance in comparison to other species (Narayanan & Bindumadhav, 2019).

The adoption of unrecognized prevention measures included the spreading of readily accessible products in the home, such as turmeric or garlic water, salt, and cow dung, as well as potentially dangerous substances (e.g., kerosene), and the erection of fencing around the property. Many of these unrecognized measures differ from those recommended by the national government (Ministry of Health & Family Welfare Government of India, 2016), WHO (WHO, 2019), and notable nongovernment organizations (MCBT, 2022), heightening calls for further research to explore the snake-deterrent efficacy of these approaches and negative ecological impacts of their potential implementation (Wood et al., 2022). Furthermore, it also identifies the importance of governing bodies' engagement and transparent communication with affected communities to mutually develop a coherent view of how to prevent snakebites (Wood et al., 2022).

4.2 | Future adoption of recognized snakebite prevention measures and the influence of social factors

A range of factors affected participants' future willingness to sleep on a raised platform, wear protective clothing on dry ground, or use a stick to check for snakes in areas of low visibility. Gender, relative wealth, and current adoption status alongside variations of perceived risk severity were all relatively important and informative predictors of future adoption willingness for specific measures. However, perceived self-efficacy and risk frequency were informative across all three behaviors and highlighted the essential need to understand context-specific idiosyncrasies before implementation to improve prevention efficacy and mitigate negative wildlife interactions (Travers et al., 2019).

Studies exploring factors that affect future adoption are limited within conservation science (Nuno et al., 2022), emphasizing the need to consider interdisciplinary insight in conservation science and practice. For example, perceived self-efficacy has also been reported in health literature as a strong driver of future adoption for disease preventative products, including the UK's CV-19 tracking app and self-testing CV-19 kits in Spain (Hernández-Padilla et al., 2020; Walrave et al., 2020). Perceived risk frequency was also an informative driver of future use, supporting conceptual models (Denninger Snyder & Rentsch, 2020) and empirical studies within coexistence literature (Noga et al., 2015). However, health literature shows men have lower levels of risk aversion and are less likely to take action to prevent disease than women (Galasso et al., 2020). Wealth is also found to negatively affect the adoption of disease prevention in lower-income nations (Ahmad et al., 2021). This is especially concerning in the case of snakebites, where we find men are less likely

Conservation Science and Practice
A Journal of the Society for Conservation Biology
Open Access
WILEY

to wear protective clothing and purchase a raised bed, despite being the most likely to suffer a venomous snakebite in rural agricultural areas of India (Suraweera et al., 2020). This elevates calls for affordable snakebite prevention in high-bite-risk areas (Malhotra et al., 2021; Rodrigo et al., 2017; Samuel et al., 2020), with a focus on individuals who perceive snakebite risk to be low.

A range of barriers affected the future adoption of snakebite prevention measures, highlighting the need for more considered prevention support to support harmonious coexistence. Practicality, financial limitations, familiarity, physical comfort, social pressure, and cultural beliefs are all key barriers reported for specific prevention measures. This is especially true for the implementation of protective clothing (boots/gloves), while commonly recommended for use within snakebite literature (Malhotra et al., 2021), where our findings show these measures carried the greatest number of barriers for implementation and reinforce the negative influence of physical discomfort alongside impracticality for future adoption (Ayode et al., 2013; D'Août et al., 2009). It is possible that such barriers are use-case specific, and it will be important to consider these factors in relation to the nature of local agricultural practice employed by affected communities as dry ground conditions may improve adoption feasibility. For example, observed resistance to the future adoption of protective clothing was largely underpinned by the nature of agricultural work in the study site (i.e., paddy fields), where participants rightly challenged the sustainable practicality and comfort of this measure in wet conditions. Participants reported fewer barriers for use in dry agricultural environments and perceived protective clothing (boots/gloves) as highly effective snakebite prevention measures.

Social and cultural barriers were less frequently reported by participants. For example, barefoot tradition in agricultural fields and feelings of embarrassment to wear shoes or protective gear. However, it is possible these factors have a disproportionate effect on the use of protective clothing and other snakebite prevention measures. This is partially because participants are less likely to raise sociocultural barriers in individual interview settings (Guest et al., 2017). Given empirical studies from sustainable management literature show these factors underpin the adoption of new farming practices within rural tropical communities (Curry et al., 2021; Dessart et al., 2019), our findings support their consideration in future related studies and reinforce the need to consider cross-disciplinary approaches for conservation challenges (Struebig et al., 2018).

It is important to note that self-reported adoption or willingness to potentially adopt mitigation measures can fall victim to social desirability bias (Nuno & John, 2015) and may not accurately reflect current or future behavior. As such, reportedly high levels of current adoption and future willingness to undertake snakebite prevention measures should be viewed with caution, especially considering the opportunistic sampling approach employed within selected agricultural communities. Regardless, to the best of our knowledge, social factors related to the current and potential future adoption of prevention measures for venomous snakebites have never been explored so extensively. Specifically, this was enabled through the use of an integrated framework (e.g., HBM), with limited prior application in conservation (Crockford et al., 2018; Nuno et al., 2022). Tools and frameworks from social science are well placed to consistently identify and prioritize key behaviors, where such are likely to vary across social or cultural contexts (Nielsen et al., 2021). The use of solid systematic frameworks, such as the HBM, should be further employed to improve the effectiveness of conflict prevention for both biodiversity and human livelihoods. This will be particularly important to achieve WHO ambitions to half snakebite deaths by 2030 and Target 4 of the Convention for Biological Diversity, where further adoption of preventatives can prevent snakebite events, promote snake conservation, and enhance more harmonious coexistence moving forward.

5 | RECOMMENDATIONS

While academic attention and organizational support for snakebite prevention has increased in recent years, a generic distribution of prevention measures will not prevent snakebites or provide capacity for snake conservation. Instead, an understanding of the factors that underpin adoption within affected communities is critical, considering the context-specific relevance of specific measures. Minimizing snakebites has important repercussions for human health and snake conservation, this study lists key recommendations to support this ambition:

1. Apply the use of the HBM, or other relevant frameworks from social science, to assess context-specific barriers and enablers for adoption before implementing snakebite prevention measures. It is likely that factors underpinning adoption may vary among communities facing similar levels of perceived snakebite risk on account of belief systems and livelihoods (i.e., agricultural practices). Understanding factors that drive adoption at more granular levels will require greater engagement between research fields, the WHO, nongovernment organizations, and governments across the tropics, alongside the use of a single holistic plan to approach such work in a complimentary fashion;

2. Rapidly assess the costs and benefits of unrecognized snakebite prevention measures. These measures are likely to be adopted more readily across communities given their bottom-up generation and support overall coexistence objectives, assuming they do not negatively interact with wildlife or natural resources required;
3. Enhance the awareness of recognized snakebite prevention measures for at-risk communities. Awareness materials should be specific to local farming and environmental conditions, building on factors that promote adoption (i.e., risk likelihood, self-efficacy, and practicality) and integrated within employee onboarding processes where applicable. As a call to action, we suggest the WHO prioritize support for snakebite prevention in tropical climates, considering current adoption frequency and future adoption willingness for recognized prevention measures compared to challenges facing the implementation of antivenom treatments (i.e., access and understanding).
4. Employ trial periods and engage local non-government organization support when or if implementing new prevention measures for adoption in affected communities. Such initiatives are likely to enhance inhabitants' confidence to use proposed measures independently and promote adoption;
5. Expand research exploring the behavioral ecology of medically significant venomous snake species at relevant spatial and temporal scales. A better understanding of venomous snake ecology in bite-risk regions could support the development of educational material and prevention strategies to avoid human–snake conflict (i.e., bite-risk areas and months).
6. Expand the provision of snake education for communities living in bite-risk areas. A better understanding of ecosystem services provided by snakes and support to distinguish between venomous or non-venomous species may reduce fear alongside blanket killing of all sighted species.
7. Finally, research the role of cues to action in the adoption of snakebite prevention measures. Where perceived snakebite likelihood is low in comparison to actual snakebite risk, cues to action may positively influence the adoption of snakebite prevention during priority seasons (rainy season) following periods of non-adoption.

AUTHOR CONTRIBUTIONS

Harrison Carter: Conceptualization; methodology; data collection; resources; investigation; formal analysis and writing. **Xavier Glaudas:** Conceptualization; review and supervision. **Romulus Whitaker:** Conceptualization and review. **Gnaneswar Chandrasekharun:** Methodology and review. **Kimberley Hockings:** Conceptualization; review and supervision. **Ana Nuno:** Conceptualization; methodology; review and supervision.

ACKNOWLEDGMENTS

Harrison Carter was supported by the University of Exeter, Madras Crocodile Bank Trust, and family crowdfunding. Ana Nuno was supported by the European Union's Horizon 2020 research and innovation programme, under a Marie Skłodowska-Curie grant [SocioEcoFrontiers No. 843865]. We are incredibly grateful to all research participants who gave their time and insight. Furthermore, this project would not have been possible without the following people: District of Thiruvarur's collector Gayathri Krishnan, member of the legislative assembly K. Poondi Kalaivanan, councillor Meenakshi Suriya Prakash, and our three research assistants Selwin Kumar J, Peter Christopher and Karthi Gowthaman Jayaraman.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Including a link to the repository used to archive their data (see policy on Data Sharing and Accessibility). Authors should also (where relevant) provide a statement of the ethics review process that was adhered to in gathering the data. Fully anonymised dataset to be made available on data dryad.

ETHICS STATEMENT

Data collection was conducted in accordance with conditions set out in the project's ethics approval conducted by the University of Exeter (Approval ID: 513153).

ORCID

Harrison Carter https://orcid.org/0009-0008-8989-7403
Ana Nuno https://orcid.org/0000-0003-4680-2378

REFERENCES

Ahmad, M., Akhtar, N., Jabeen, G., Irfan, M., Khalid Anser, M., Wu, H., & Işık, C. (2021). Intention-based critical factors affecting willingness to adopt novel coronavirus prevention in Pakistan: Implications for future pandemics. *International Journal of Environmental Research and Public Health*, *18*, 6167.

Alangode, A., Rajan, K., & Nair, B. G. (2020). Snake antivenom: Challenges and alternate approaches. *Biochemical Pharmacology*, *181*, 114135.

Alirol, E., Sharma, S. K., Bawaskar, H. S., Kuch, U., & Chappuis, F. (2010). Snake bite in South Asia: A review. *PLoS Neglected Tropical Diseases*, *4*, e603.

Allocco, A. L. (2013). Fear, reverence and ambivalence: Divine snakes in contemporary south India. *Religions of South Asia*, *7*, 230–248.

Al-Sabbagh, M. Q., Al-Ani, A., Mafrachi, B., Siyam, A., Isleem, U., Massad, F. I., Alsabbagh, Q., & Abufaraj, M. (2022). Predictors of adherence with home quarantine during COVID-19 crisis: The case of health belief model. *Psychology, Health & Medicine*, *27*, 215–227.

Alves, R., Silva, V. N., Trovão, D. M., Oliveira, J. V., Mourão, J. S., Dias, T. L., Alves, Â. G., Lucena, R. F., Barboza, R. R., & Montenegro, P. F. (2014). Students' attitudes toward and knowledge about snakes in the semiarid region of Northeastern Brazil. *Journal of Ethnobiology and Ethnomedicine*, *10*, 30.

Anderson, D. R., & Burnham, K. P. (2002). Avoiding pitfalls when using information-theoretic methods. *Journal of Wildlife Management*, *66*, 912–918.

Arnold, T. W. (2010). Uninformative parameters and model selection using Akaike's information criterion. *Journal of Wildlife Management*, *74*, 1175–1178.

Ayode, D., McBride, C. M., de Heer, H. D., Watanabe, E., Gebreyesus, T., Tora, A., Tadele, G., & Davey, G. (2013). A qualitative study exploring barriers related to use of footwear in rural highland Ethiopia: Implications for neglected tropical disease control. *PLoS Neglected Tropical Diseases*, *7*, e2199.

Balakrishnan, P. (2010). An education programme and establishment of a citizen scientist network to reduce killing of non-venomous snakes in Malappuram district, Kerala, India. *Conservation Evidence*, *7*, 9–15.

Barton, K. (2018). MuMIn: Multi-model inference. R package. Cran-R, 1, 289–290.

Beaupre, S. J., & Douglas, L. E. (2009). Snakes as indicators and monitors of ecosystem properties. In S. J. Mullin & R. A. Seigel (Eds.), *Snakes: Ecology and conservation* (pp. 244–261). Cornell University Press.

Budnukaeku, A., Ichendu, C., & Irene, D. (2021). Human impacts on keystone species within the ecological food web. *MOJ Ecology & Environmental Sciences*, *6*, 182–186.

Bulfone, T. C., Samuel, S. P., Bickler, P. E., & Lewin, M. R. (2018). Developing small molecule therapeutics for the initial and adjunctive treatment of snakebite. *Journal of Tropical Medicine*, *2018*, 4320175.

Carter, N. H., Baeza, A., & Magliocca, N. R. (2020). Emergent conservation outcomes of shared risk perception in human-wildlife systems. *Conservation Biology*, *34*, 903–914.

Chowdhury, M. A. W., Müller, J., & Varela, S. (2021). Climate change and the increase of human population will threaten conservation of Asian cobras. *Scientific Reports*, *11*, 18113.

Crockford, C., Dean, A., Reid, S., & Dean, J. (2018). Conservation values and risk of handling bats: Implications for one health communication. *EcoHealth*, *15*, 682–687.

Curry, G. N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E., & Nailina, R. (2021). Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. *Journal of Rural Studies*, *88*, 422–431.

da Silva, A. M., Colombini, M., Moura-da-Silva, A. M., de Souza, R. M., Monteiro, W. M., & Bernarde, P. S. (2019). Ethno-knowledge and attitudes regarding snakebites in the Alto Juruá region, Western Brazilian Amazonia. *Toxicon*, *171*, 66–77.

D'Août, K., Pataky, T. C., De Clercq, D., & Aerts, P. (2009). The effects of habitual footwear use: Foot shape and function in native barefoot walkers. *Footwear Science*, *1*, 81–94.

Denninger Snyder, K., & Rentsch, D. (2020). Rethinking assessment of success of mitigation strategies for elephant-induced crop damage. *Conservation Biology*, *34*, 829–842.

Dessart, F. J., Barreiro-Hurlé, J., & van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review. *European Review of Agricultural Economics.*, *46*, 417–471.

Dickman, A. J., Hazzah, L., Carbone, C., & Durant, S. M. (2014). Carnivores, culture and 'contagious conflict': Multiple factors influence perceived problems with carnivores in Tanzania's Ruaha landscape. *Biological Conservation*, *178*, 19–27.

Fortin, D., Brooke, C. F., Lamirande, P., Fritz, H., McLoughlin, P. D., & Pays, O. (2020). Quantitative spatial ecology to promote human-wildlife coexistence: A tool for integrated landscape management. *Frontiers in Sustainable Food Systems*, *4*, 600363.

Galasso, V., Pons, V., Profeta, P., Becher, M., Brouard, S., & Foucault, M. (2020). Gender differences in COVID-19 attitudes and behavior: Panel evidence from eight countries. *Proceedings of the National Academy of Sciences of the United States of America*, *117*, 27285–27291.

Government of Tamil Nadu. (2017). District Human Development Report 2017, Thiruvarur District, State Planning Commission Tamil Nadu. Available from https://spc.tn.gov.in/DHDR/Thiruvarur.pdf

Guest, G., Namey, E., Taylor, J., Eley, N., & McKenna, K. (2017). Comparing focus groups and individual interviews: Findings from a randomized study. *International Journal of Social Research Methodology*, *20*, 693–708.

Habib, A. G., & Brown, N. I. (2018). The snakebite problem and antivenom crisis from a health-economic perspective. *Toxicon*, *150*, 115–123.

Harris, J. B., Faiz, M. A., Rahman, M. R., Jalil, M. M., Ahsan, M. F., Theakston, R. D. G., Warrell, D. A., & Kuch, U. (2010). Snake bite in Chittagong Division, Bangladesh: A study of bitten patients who developed no signs of systemic envenoming. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *104*, 320–327.

Harrison, R. A., Hargreaves, A., Wagstaff, S. C., Faragher, B., & Lalloo, D. G. (2009). Snake envenoming: A disease of poverty. *PLoS Neglected Tropical Diseases*, *3*, e569.

Hernández-Padilla, J. M., Granero-Molina, J., Ruiz-Fernández, M. D., Dobarrio-Sanz, I., López-Rodríguez, M. M., Fernández-Medina, I. M., Correa-Casado, M., & Fernández-Sola, C. (2020). Design and psychometric analysis of the COVID-19 prevention, recognition and home-management self-efficacy scale. *International Journal of Environmental Research and Public Health*, *17*, 4653.

IUCN. (2022). International Union for Conservation of Nature Red List, International Union for Conservation of Nature. Available from https://www.iucnredlist.org/

Jadhav, P. L., Chavan, S. P., & Trimukhe, H. S. (2018). Snake species diversity and their distribution in and around Nanded city, Maharashtra, India. *Journal of Entomology and Zoology Studies*, *6*, 1855–1860.

Janani, S., Maheshwaran, E., Leenu, J., Samuel, T., & Raveen, R. (2016). Diversity of snakes rescued at Chennai, Tamil Nadu, India. *International Journal of Fauna and Biological Studies*, *3*, 81–86.

Jayawardana, S., Arambepola, C., Chang, T., & Gnanathasan, A. (2020). Prevalence, vulnerability and epidemiological characteristics of snakebite in agricultural settings in rural Sri Lanka: A population-based study from South Asia. *PLoS One*, *15*, e0243991.

Jones, C. J., Smith, H., & Llewellyn, C. (2014). Evaluating the effectiveness of health belief model interventions in improving adherence: A systematic review. *Health Psychology Review*, *8*, 253–269.

Kontsiotis, V. J., Rapti, A., & Liordos, V. (2022). Public attitudes towards venomous and non-venomous snakes. *Science of the Total Environment*, *831*, 154918.

Kularatne, A. M., Silva, A., Maduwage, K., Ratnayake, I., Walathara, C., Ratnayake, C., Mendis, S., & Parangama, R. (2014). Victims' response to snakebite and socio-epidemiological factors of 1018 snakebites in a tertiary care hospital in Sri Lanka. *Wilderness & Environmental Medicine*, *25*, 35–40.

Landry Yuan, F., Ballullaya, U. P., Roshnath, R., Bonebrake, T. C., & Sinu, P. A. (2020). Sacred groves and serpent-gods moderate human–snake relations. *People and Nature*, *2*, 111–122.

Lange, G. (2019). Cobra deities and divine cobras: The ambiguous animality of Nāgas. *Religions*, *10*, 454.

Laxme, R. S., Khochare, S., de Souza, H. F., Ahuja, B., Suranse, V., Martin, G., Whitaker, R., & Sunagar, K. (2019). Beyond the 'big four': Venom profiling of the medically important yet neglected Indian snakes reveals disturbing antivenom deficiencies. *PLoS Neglected Tropical Diseases*, *13*, e0007899.

Luiselli, L., Sale, L., Akani, G. C., & Amori, G. (2020). Venomous snake abundance within snake species' assemblages worldwide. *Diversity*, *12*, 69.

Madden, F., & McQuinn, B. (2014). Conservation's blind spot: The case for conflict transformation in wildlife conservation. *Biological Conservation*, *178*, 97–106.

Madras Crocodile Bank Trust (MCBT). (2022). Snakebite Mitigation, Madras Crocodile Bank Trust Website. Available from https://madrascrocodilebank.org/snakebite_mitigation

Malhotra, A., Wüster, W., Owens, J. B., Hodges, C. W., Jesudasan, A., Gnaneswar, C., Kartik, A., Christopher, P., Louies, J., Naik, H., Santra, V., Kuttalam, S. R., Attre, S., Sasa, M., Bravo-Vega, C., & Murray, K. A. (2021). Promoting co-existence between humans and venomous snakes through increasing the herpetological knowledge base. *Toxicon: X*, *12*, 100081.

Ministry of Health & Family Welfare. (2016). Management of snake bite, Government of India. Available from https://nhm.gov.in/images/pdf/guidelines/nrhm-guidelines/stg/Snakebite_QRG.pdf

Mise, Y. F., Lira-da-Silva, R. M., & Carvalho, F. M. (2016). Agriculture and snakebite in Bahia, Brazil—An ecological study. *Annals of Agricultural and Environmental Medicine*, *23*, 416–419.

Narayanan, Y., & Bindumadhav, S. (2019). 'Posthuman cosmopolitanism' for the Anthropocene in India: Urbanism and human-snake relations in the Kali Yuga. *Geoforum*, *106*, 402–410.

Nielsen, K. S., Marteau, T. M., Bauer, J. M., Bradbury, R. B., Broad, S., Burgess, G., Burgman, M., Byerly, H., Clayton, S., & Espelosin, D. (2021). Biodiversity conservation as a promising frontier for behavioural science. *Nature Human Behaviour*, *5*, 550–556.

Noga, S. R., Kolawole, O. D., Thakadu, O., & Masunga, G. (2015). Small farmers' adoption behaviour: Uptake of elephant crop-raiding deterrent innovations in the Okavango Delta, Botswana. *African Journal of Science, Technology, Innovation and Development*, *7*, 408–419.

Nuno, A., Chesney, C., Wellbelove, M., Bersacola, E., Kalema-Zikusoka, G., Leendertz, F., Webber, A. D., & Hockings, K. J. (2022). Protecting great apes from disease: Compliance with measures to reduce anthroponotic disease transmission. *People and Nature*, *4*, 1387–1400.

Nuno, A., & John, F. A. S. (2015). How to ask sensitive questions in conservation: A review of specialized questioning techniques. *Biological Conservation*, *189*, 5–15.

Onyishi, I. E., Nwonyi, S. K., Pazda, A., & Prokop, P. (2021). Attitudes and behaviour toward snakes on the part of Igbo people in southeastern Nigeria. *Science of the Total Environment*, *763*, 143045.

Pandey, D. P., Subedi Pandey, G., Devkota, K., & Goode, M. (2016). Public perceptions of snakes and snakebite management: Implications for conservation and human health in southern Nepal. *Journal of Ethnobiology and Ethnomedicine*, *12*, 22.

Paramasivan, C., & Pasupathi, R. (2016). An overview of Cauvery Delta Zone in Tamil Nadu. *International Journal of Trend in Research and Development*, *3*, 399–403.

Pinheiro, L. T., Rodrigues, J. F. M., & Borges-Nojosa, D. M. (2016). Formal education, previous interaction and perception influence the attitudes of people toward the conservation of snakes in a large urban center of northeastern Brazil. *Journal of Ethnobiology and Ethnomedicine*, *12*, 25.

Rádlová, S., Janovcová, M., Sedláčková, K., Polák, J., Nácar, D., Peléšková, Š., Frynta, D., & Landová, E. (2019). Snakes represent emotionally salient stimuli that may evoke both fear and disgust. *Frontiers in Psychology*, *10*, 1085.

Reiserer, R. S., Schuett, G. W., & Greene, H. W. (2018). Seed ingestion and germination in rattlesnakes: Overlooked agents of rescue and secondary dispersal. *Proceedings of the Royal Society B: Biological Sciences*, *285*, 20172755.

Robinson OC. (2014). Sampling in interview-based qualitative research: A theoretical and practical guide. *Qualitative research in psychology*, *11*, 25–41.

Rodrigo, C., Kirushanthan, S., & Gnanathasan, A. (2017). Prevention of krait bites by sleeping above ground: Preliminary results from an observational pilot study. *Journal of Occupational Medicine and Toxicology*, *12*, 10.

RStudio Team. (2022). *RStudio: Integrated development*. Environment for R. RStudio.

Salve, P., Vatavati, S., & Hallad, J. (2020). Clustering the envenoming of snakebite in India: The district level analysis using Health Management Information System data. *Clinical Epidemiology and Global Health*, *8*, 733–738.

Samuel, S. P., Chinnaraju, S., Williams, H. F., Pichamuthu, E., Subharao, M., Vaiyapuri, M., Arumugam, S., Vaiyapuri, R., Baksh, M. F., & Patel, K. (2020). Venomous snakebites: Rapid action saves lives—A multifaceted community education programme increases awareness about snakes and snakebites among the rural population of Tamil Nadu, India. *PLoS Neglected Tropical Diseases*, *14*, e0008911.

Singh, A., Goel, S., Singh, A. A., Goel, A. K., Chhoker, V. K., Goel, S., Naik, S. M., & Kaur, M. (2015). An epidemiological study of snakebites from rural Haryana. *International Journal of Advanced Medical and Health Research*, *2*, 39.

Small, E. (2021). In defence of the world's most reviled vertebrate animals: Part 1: 'Lower' species (sharks, snakes, vultures, frogs & toads). *Biodiversity*, *22*, 159–193.

Struebig, M. J., Linkie, M., Deere, N. J., Martyr, D. J., Millyanawati, B., Faulkner, S. C., Le Comber, S. C., Mangunjaya, F. M., Leader-Williams, N., & McKay, J. E. (2018). Addressing human-tiger conflict using socio-ecological information on tolerance and risk. *Nature Communications*, *9*, 3455.

Su, K., Zhang, H., Lin, L., Hou, Y., & Wen, Y. (2022). Bibliometric analysis of human–wildlife conflict: From conflict to coexistence. *Ecological Informatics*, *68*, 101531.

Suraweera, W., Warrell, D., Whitaker, R., Menon, G., Rodrigues, R., Fu, S. H., Begum, R., Sati, P., Piyasena, K., & Bhatia, M. (2020). Trends in snakebite deaths in India from 2000 to 2019 in a nationally representative mortality study. *eLife*, *9*, e54076.

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. *The SAGE handbook of qualitative research in psychology*, *2*, 17–37.

Travers, H., Selinske, M., Nuno, A., Serban, A., Mancini, F., Barychka, T., Bush, E., Rasolofoson, R. A., Watson, J. E., & Milner-Gulland, E. (2019). A manifesto for predictive conservation. *Biological Conservation*, *237*, 12–18.

Vaiyapuri, S., Vaiyapuri, R., Ashokan, R., Ramasamy, K., Nattamaisundar, K., Jeyaraj, A., Chandran, V., Gajjeraman, P., Baksh, M. F., & Gibbins, J. M. (2013). Snakebite and its socio-economic impact on the rural population of Tamil Nadu, India. *PloS One*, *8*, e80090.

Wagenmakers, E.-J., & Farrell, S. (2004). AIC model selection using Akaike weights. *Psychonomic Bulletin & Review*, *11*, 192–196.

Walrave, M., Waeterloos, C., & Ponnet, K. (2020). Adoption of a contact tracing app for containing COVID-19: A health belief model approach. *JMIR Public Health and Surveillance*, *6*, e20572.

Waring, T. M. (2012). Cooperation dynamics in a multiethnic society: A case study from Tamil Nadu. *Current Anthropology*, *53*, 642–649.

Whitaker, P. B., & Shine, R. (2000). Sources of mortality of large elapid snakes in an agricultural landscape. *Journal of Herpetology*, *34*, 121–128.

Whitaker, R., & Martin, G. (2015). Diversity and distribution of medically important snakes of India. In P. Gopalakrishnakone, A. Faiz, R. Fernando, C. Gnanathasan, A. Habib, & C. C. Yang (Eds.), *Clinical toxinology in Asia Pacific and Africa* (pp. 115–136). Springer.

Whitaker, R., & Whitaker, S. (2012). Venom, antivenom production and the medically important snakes of India. *Current Science*, *103*, 635–643.

Williams, H. F., Layfield, H. J., Vallance, T., Patel, K., Bicknell, A. B., Trim, S. A., & Vaiyapuri, S. (2019). The urgent need to develop novel strategies for the diagnosis and treatment of snakebites. *Toxins*, *11*, 363.

Wojnowski, D. (2010). Gender-appropriate responses to snakes in Kenya: Culture, concepts and context. *International Journal of Interdisciplinary Social Sciences*, *5*, 1–12.

Wong, M. C., Wong, E. L., Huang, J., Cheung, A. W., Law, K., Chong, M. K., Ng, R. W., Lai, C. K., Boon, S. S., & Lau, J. T. (2021). Acceptance of the COVID-19 vaccine based on the health belief model: A population-based survey in Hong Kong. *Vaccine*, *39*, 1148–1156.

Wood, L., Ngari, C., Parkurito, S., Barnes, K., Otundo, D., Misiani, D. A., Kephah, G. M., Trelfa, A., Olouch, G. O., & Harrison, R. A. (2022). "Then they prayed, they did nothing else, they just prayed for the boy and he was well": A qualitative investigation into the perceptions and behaviours surrounding snakebite and its management in rural communities of Kitui county, Kenya. *PLoS Neglected Tropical Diseases*, *16*, e0010579.

World Bank Group. (2017). Tamil Nadu: Poverty, growth and inequality. Public disclosure, World Bank Group. Available from https://documents1.worldbank.org/curated/en/380971504177733539/pdf/119267-BRI-P157572-Tamil-Nadu-Poverty.pdf

World Health Organisation (WHO). (2019). *Snakebite envenoming: A strategy for prevention and control*. WHO Press. Available from https://apps.who.int/iris/handle/10665/324838

Zacarias, D., & Loyola, R. (2019). Climate change impacts on the distribution of venomous snakes and snakebite risk in Mozambique. *Climatic Change*, *152*, 195–207.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Carter, H., Glaudas, X., Whitaker, R., Chandrasekharun, G., Hockings, K., & Nuno, A. (2024). Venomous snakebites: Exploring social barriers and opportunities for the adoption of prevention measures. *Conservation Science and Practice*, *6*(2), e13063. https://doi.org/10.1111/csp2.13063