



Integrating lay knowledge and practice into snakebite prevention and care in central Africa, a hotspot for envenomation

Romain Duda^a, Wuelton M. Monteiro^{b,c}, Tamara Giles-Vernick^{a,*}

^a Anthropology & Ecology of Disease Emergence Unit, Institut Pasteur, Paris, France

^b School of Health Sciences, Universidade Do Estado Do Amazonas, Manaus, Brazil

^c Department of Research, Fundação de Medicina Tropical Dr. Heitor Vieira Dourado, Manaus, Brazil

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ABSTRACT

The WHO has identified the goal of halving deaths and disability from snakebite envenomation (SBE) by 2030 through a four-pillar program that promotes accessible and affordable treatments, strengthens health systems, promotes community and multi-level engagement, and mobilizes partnerships, coordination and resources to advocate for global action. This initiative could accelerate multi-disciplinary research and action in central Africa, a “hotspot” for SBE, but it offers little specific guidance about anthropological research to be conducted. This commentary develops that research agenda. It surveys anthropological, ethnohistorical investigations in the central African forest to elaborate the socio-cultural and historical significance and practices around snakes and snakebites. It draws from south and southeast Asian and Latin American literatures to illustrate anthropological contributions to SBE research. It then outlines a Central African research agenda employing ethnobiological investigation of snake ecologies, participatory evaluations of humans-snake contacts, and interviews and participant-observation of local prevention and treatment practices and knowledge. This research will co-develop policies and practices with forest communities and leaders and regional and national authorities to reduce the burden of SBE.

1. Introduction

Snakebite envenomation (SBE), a World Health Organization (WHO)-designated neglected tropical disease, has its most adverse consequences in lower- and middle-income countries (LMICs). There, a higher diversity and abundance of venomous snakes exist; more subsistence activities bring people into contact with such snakes, and under-resourced health systems offer poor (or no) access to antivenoms (Gutiérrez et al., 2006; Gutiérrez et al., 2010; Halilu et al., 2019; Williams et al., 2010). In addition, a lack of health education and low awareness of biomedical treatments contribute to SBE mortality (Chippaux, 2017; Longbottom et al., 2018). The WHO seeks to halve deaths and disability from envenomation by 2030 through a four-pillar program that promotes accessible and affordable treatments, strengthens health systems, facilitates community and multi-level engagement to take action, and mobilizes partnerships, coordination and resources to advocate for global action (Williams et al., 2019). This initiative can deepen understanding of envenomation and improve public education, prevention, and care (Babo Martins et al., 2019; da

Silva et al., 2019; Gutiérrez et al., 2015).

This important initiative could be used to accelerate multi-disciplinary research and action in central Africa, a “hotspot” for SBE (Longbottom et al., 2018). The WHO supports investigation of “socio-cultural, economic, political and geophysical influences on perceptions of snakebite and treatment-seeking by populations at risk” to “change behaviour, policy and practice” (WHO, 2019; Williams et al., 2019). But beyond the objective to alter “behaviour, policy and practice”, there is little specific guidance about what “sociocultural” or broader anthropological research should be conducted. In central Africa, this research-action agenda could draw on a rich foundation of anthropological and historical research revealing how Central African people have woven snakes into their own histories, socio-political and ecological relations, and understandings of misfortune. Building on central African knowledge about the material, symbolic and supernatural significance of snakes in human lives could achieve José María Gutiérrez’s call to bring diverse disciplinary and participatory perspectives into genuine dialogue, and ultimately to improve prevention and treatment of SBE (Gutiérrez, 2020). We argue here that the full integration of

* Corresponding author.

E-mail address: tamara.giles-vernick@pasteur.fr (T. Giles-Vernick).

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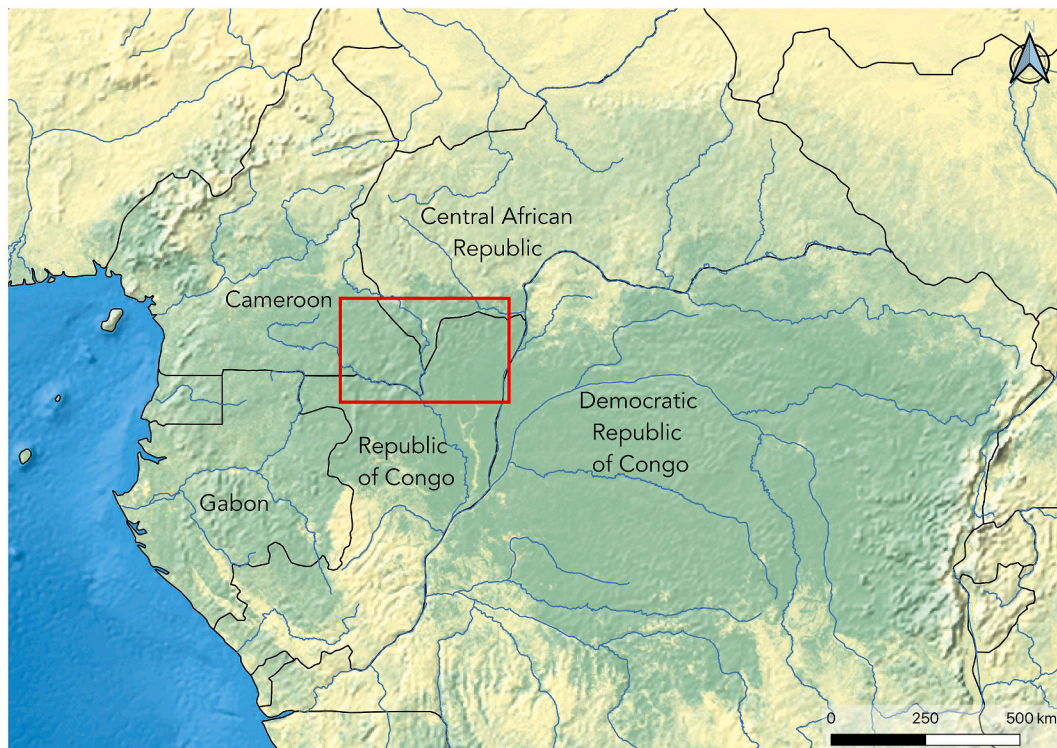


Fig. 1. Map of central Africa.

anthropological and ethnohistorical research into the SBE research and action could engage central Africans to contribute to meaningful SBE prevention and treatment interventions. Working closely with central African forest inhabitants and leaders, this effort could yield grounded insight into the historical, socio-political, ecological and cultural processes and practices that bring people and snakes into engagement, shed light on care practices and interactions with informal healers, formal health structures and health workers, and highlight available resources and engagements of health authorities and decision-makers.

We review here the epidemiology of SBE and draw from our ethnohistorical and anthropological knowledge of snakes in the northern equatorial African rainforest to propose an integration of participatory anthropological research of snakebite prevention and care. We draw inspiration from South and Southeast Asian and Latin American SBE literatures, which have more actively pursued anthropological perspectives. Our reflection is itself an experimental, cross-disciplinary dialogue, written on one hand by two anthropologist-ethnohistorians who have conducted long term ethnozoological, historical, and medical anthropological research with central Africans – but not on SBE – and on the other hand, by a long-standing specialist working at the intersection of the epidemiology and social sciences of snakebite envenomation in the Amazon.

2. Overview of Central African societies

Rural and forest populations in Central Africa have highly varied histories and sociocultural relations (see Fig. 1). In the northern equatorial forests where Romain Duda and Tamara Giles-Vernick have conducted research, for instance, these populations generally lead subsistence-based livelihoods. Resource accumulation tends to be low and short-term, although in the pre-colonial past, some societies derived relatively short-term wealth through the accumulation of followers (Guyer and Belinga, 1995).

Anthropological research in the equatorial forests distinguish between societies based on resources exploitation and shared identities: those historically reliant on agriculture through swidden (slash-and-

burn) agriculture, and those predominantly oriented towards forest resource exploitation (hunting, fishing, gathering) (Klieman, 2003; Thomas et al., 1981; Vansina, 1990). Nevertheless, these distinctions are far more blurred today: agricultural producers have long engaged in considerable hunting, fishing and gathering, and multiple hunting-gathering populations have in the past several decades engaged in increased agricultural production (Dounias and Froment, 2011; Rupp, 2011). These modes of subsistence, highly dependent of the forest environment, vary across the central African forest according to local ecological conditions and material cultures. Social organizations, which are now parallel and fit into state governance also vary, from more hierarchical, chieftaincy-based to more egalitarian societies (e.g. Baka, Bayaka) (Tonda, 2005).

Local informal health care generally includes familial remedies employing herbal (roots, barks, leaves) and specialist treatments to resolve more serious cases. Ill health tends to be associated with an investigation of causation, which may involve the bodily site of the symptoms or may be linked to a causal agent in the environment or to individual behaviors. Illnesses whose symptoms are severe (or leading to a rapid death) are often associated with witchcraft (Epelboin, 2017; Rosny, 1981). People whose illnesses have been associated with this invisible world are therefore directed to specialist healers providing treatment and psychosocial care.

3. The epidemiology of snakebites in Central Africa

As one of the most neglected tropical diseases, SBE constitutes a significant public health burden in central Africa (Halilu et al., 2019). The risk of SBE is difficult to evaluate, not only because of patchy hospital statistics, but also because forest inhabitants and rural populations do not tend to seek biomedical care for snakebites (Balde et al., 2005). A meta-analysis of published studies from sub-Saharan Africa between 1970 and 2010 estimated mortality at more than 7000 cases per year, although this figure may be an underestimate (Chippaux, 1998, 2011; Halilu et al., 2019).

The conditions producing a potential underestimate, incomplete

statistics and low care-seeking for SBE in central Africa result partly from multiple scarcities, notably poor antivenom (AV) availability and affordability and weak rural health care structures (Chippaux, Mas-sougbodji, Diouf, Baldé and Boyer, 2015; Ditekemena et al., 2020; Habib et al., 2020). Out of 46 AV producers globally, the African continent has just one in South Africa, which manufactures AV in relatively low volumes and at comparatively high costs (\$US 315 per dose) (Habib et al., 2020). Few AVs are available in African markets (Potet et al., 2019). Additionally, long distances between the village and health center entail substantial delays in medical care-seeking. Medical personnel lack appropriate training for SBE, and local populations tend to favor traditional healing practices over biomedical solutions (Bokata, 2005; Chippaux, 2011; Habib et al., 2015). Although urban residents are more likely to seek formal health care for snakebites, rural inhabitants primarily use traditional pharmacopoeia. Several authors contend that this therapeutic choice results partly from a dearth of high-quality hospital treatments (Akiana et al., 2005; Balde et al., 2005; Chippaux, 2002; Chippaux and Diallo, 2002). Some studies advocate training local populations to carry out “life-saving gestures”, including immobilizing the affected limb, wound cleaning, and tight bandaging (Chippaux, 2002; Chippaux, Diédhiou and Stock, 2007; Fry, 2018).

Central Africa’s high SBE burden is also a consequence of climatic, ecological and economic features that bring humans and snakes into engagement. Climate change affects human-snake contacts by increasing geographical ranges of some snakes or modifying their annual activity periods (Needleman et al., 2018). Central African forests also have high ophidian diversity, elevating the risk of SBE for human inhabitants. In addition, rural populations depend on subsistence activities in sites that disturb or overlap with snake habitats (Chippaux, 2006). Snakes tend to nest and hunt in fields that attract rodents searching for cassava, a starchy staple cultivated in central Africa. Harvesting crops and opening of new fallows disturb nesting snakes, bringing them into more frequent contact with people. Large agro-industrial plantations are also risky sites for snake contact and snakebites (Oodio et al., 2005); such sites often select for species according to the type of crop (Chippaux, 2006).

The few epidemiological studies carried out in equatorial Africa show that most bites affect active men and women between 20 and 40 years old. In forest areas, those experiencing bites are mostly bitten during agricultural activities (40 %), walking (24 %), hunting (8 %), or sleeping at home (6 %) (Chippaux, 2006, 2011; Tchoffo et al., 2019). Forest and rural housing, constructed from locally fabricated bricks, wattle-and-daub, forest vines and leaves, or rejected planks from local lumber companies, generally do not offer sufficient protection from snakes, which can seek refuge indoors and then bite human inhabitants. SBE tends to occur at times of intensive agricultural activities, in the daytime and the early rainy season (Bokata, 2005; Chippaux, 2006; Tchoffo et al., 2019). Most snakes posing a real danger to humans belong to two families: the Elapidae (mambas and cobras) and the Viperidae (Chippaux, 1998).

4. Significance of snakes in Central Africa

At once mythical agents, embodiments of evil, and vectors of sorcery, snakes have accumulated rich historical and anthropological significance in central African forests and are thus highly ambiguous as agents, objects, and vectors. Attending to these ambiguities is important, since they may shape how contemporary central Africans respond to snakes and snakebites.

Venomous snakes and primates (including humans) have shared the forest for millennia. Growing evidence suggests that primates long ago developed anti-predatory adaptations to snakes (Harris et al., 2021; Isbell, 2006). If snakes’ predatory pressure has produced humans’ fear response (Hoehl et al., 2017; Öhman and Mineka, 2003), it may have also shaped human complex understandings of snakes. Indeed, snakes appear in many origin stories of humanity, and central Africa is no

exception. It has been argued that widespread narratives involving mythical snakes (frequently associated with water) spread along migration routes from the Paleolithic period (d’Huy, 2016). Snakes have figured prominently into the beginnings of specific linguistic groups in central Africa. Beti, Kako and Mpiemu-speakers in the northern equatorial forest, for instance, recount early migration and settlement stories in which their ancestors crossed specific rivers on the back of a large snake, subsequently settling in their current zones of habitation (Giles-Vernick, 2002; Quinn, 2006). Mpiemu speakers recounted that their ancestors crossed the Sangha river on the back of the snake, thinking that it was a large forest vine. When one of the crossing people noted that they were on a snake, not a vine, the snake plunged into the river, leaving speakers of the same language separated by the river (Giles-Vernick, 2002).

Snakes, frequently associated with rainbow, rains, waters, and seasonal changes, have long been attributed symbolic powers of supernatural origin (Bonhomme, 2006; Heusch, 2007; Laburthe-Tolra, 1985). Although snake worship on the African continent was in the past been linked to and fertility, more than a century of Christian missionization has altered this practice and may have led to reinterpretations of snakes as a vector of witchcraft (Balla-Ndegue, 2015; Hamby, 1931; Rosny, 1981). Snakes now occupy a prominent place among other “mystical” animals, including leopards, gorillas, and chimpanzees, whose charismatic behaviors and appearances more broadly attract human attention and theorization (Lorimer, 2015; Sperber, 1996). They are seen to share with these animals the capacity to change their appearances and to serve as vehicles for powerful human beings to inflict harm on others. In local narratives, snakes’ predatory behavior is linked to witchcraft, which is understood in terms of a quest for accumulation and wealth. Such occult practices are part of a zero-sum game: one person’s accumulation leads to another’s loss, in societies where inequality is not well-tolerated (Cinnamon, 2002; Tonda, 2005). Snakes are also frequently viewed as emissaries of water spirits, such as Mami Wata, a water-dwelling goddess of accumulation who drags victims to their deaths by drowning (Drewal, 1988; Paxson, 1983; Van Stipriaan, 2003).

Contributing to this ambiguity is a powerful human avoidance and intolerance of snakes. Although some studies examine farmers’ interactions with snakes, we have not identified published studies examining SBE among the equatorial forest hunter-gatherer populations. Forest populations, however, engage in practices that can facilitate SBE: they move considerable distances each day and in recent decades, have adopted agricultural practices, opening forest plots to cultivate cassava and bananas. These populations tend to be especially reluctant to seek biomedical treatment, fearing stigmatization and discrimination encountered in health care structures and preferring instead local healers. Hunter-gatherer populations, such as Baka (Cameroon, Gabon, Republic of Congo) and Bayaka (Central African Republic and Republic of Congo), experience relatively high mortality because of accidents, and snakebites figure importantly in this cause of death (Dounias and Froment, 2011). Hunter-gatherer populations with whom we have worked consider the physical encounter with snakes to be unambiguously negative, and thus systematically kill them. Even when a snake slips out of sight in the forest, people might pursue to kill it, most often with a machete, to prevent a chance encounter or a bite. Snake killing is therefore conducted at risk to its human pursuers.

In addition to killing snakes, forest inhabitants engage in other practices to avoid contact with snakes. Many Bayaka believe that aggressive animals like venomous snakes are more likely to attack gestating women and their husbands, as well as menstruating women (Lewis, 2002). For this reason, Bayaka women often move together through the forest in large groups to react quickly to a snake. In contrast to male hunters, who move quietly so as not to scare off game, women often make noise in the forest, which may protect them from snakes. Forest dwelling populations hurry home at dusk to avoid snakes and steer clear of nighttime movement, except when night hunting. They take protective measures in villages and forest camps against snakes, by

cleaning and weeding to prevent snakes from hiding in weeds and tall grasses. Such actions galvanize snakes to flee and thus may temporarily increase human-snake encounters.

Snake bite is also the most common cause of canine death, most notably among hunting dogs (Lupo, 2011; Oishi, 2018). Snakes may permit a human owner to pass, but then attack the owner's dog (Thomas, 1981–2014). In Central African Republic, some owners tie cords, widely used for protection, to a dog's neck to prevent snakebites (Giles-Vernick, 2002; Thomas et al., 1981).

Although many Central African societies do not consider snakes to be edible, forest populations may consume large, opportunistically-killed snakes, such as Gaboon vipers (*Bitis gabonica*). Before consuming venomous snakes, Baka, Bayaka and other forest inhabitants will meticulously extract the snake's venom pouch or burn its head. Snake meat consumption is, however, the subject of gender- and generation-specific prohibitions commonly related to sexual relations, procreation, and childbirth. Following a common analogical theory (i.e. a cause-and-effect relationship between the disease or symptoms and an animal evoking an illness or disorder), Bayaka and Baka people, for instance, link certain health problems with the proscribed consumption of snake meat. Delayed walking or spinal deformities in a child may be attributed to the mother's snake meat consumption during pregnancy or following childbirth (Epelboin, 2017).

Our observations in Central African forests and rural areas reveal that among Baka, Bayaka, and Mpiemu societies, dreaming about or unexpectedly encountering a snake is frequently interpreted as an omen of impending misfortune (Laburthe-Tolra, 1985). Among Baka peoples in southern Cameroon, magic has its origins in a mythical father of all snakes, Yoli. All bites and stings that Baka sustain in the forest from thorns, bees, spiny fish or electric fish are caused by Yoli. Yoli never manifests in his true form; he appears to humans as events such as floods, or as other animals. Yoli imitates the cries of these animals to attract people, and then stings them to transmit "Yoli sickness". Victims experience this illness as an electric shock, leading to paralysis, swelling, abscess, and weight loss.

Equatorial African forest inhabitants tend to rely on home care and local healers to treat snake bites. Although there is a dearth of AV, long distances to health care centers, and low capacity to treat SBE, preferences for treatment by local healers and widely accepted treatments also shape forest inhabitants' care-seeking behaviors. Among central African forest inhabitants with whom we have worked, snakebite is not just about envenomation, but can signify a message, a spell cast by an enemy, or a punishment for a social transgression. Snakebite treatment must therefore address the effects of venom and the perceived cause of the harm. The healer identifies the underlying cause of the accident and then acts to restore patient's health and psychological well-being, healing the social relations that brought the victim and perpetrator into engagement through the snake.

Whereas certain observers from the global north have reduced local care-seeking and practices for SBE to "harmful techniques", these care practices are also crucial forms of psychosocial care. To be sure, certain practices may be dangerous and can lead to delays in formal care (Chippaux, 2006; Pugh and Theakston, 1987). Yet a primary purpose of such local healing practices is less to extract a specific toxic substance than to remove a symbolic harm and to re-establish a ruptured equilibrium between humans, spirits and the forest. Use of the Black Stone is one such healing practice, which seeks to redress the social and spiritual harm caused by a snakebite. Made from charred bovid bone and applied to the bite to extract snake venom, it was introduced by the Pères Blancs (White Fathers) missionaries in the 19th century and is still used in some health centers. Although it cannot entirely extract toxins (Chippaux et al., 2007; Epelboin, 1985, 2019), the Black Stone, similar to other acts of symbolic extraction, offers psychological relief to a snakebite victim and the victim's social group (Epelboin, 1985). Better insight into the significance of such treatment preferences and practices can be productively integrated into enhanced SBE prevention and care programs

and facilitate the engagement and active participation local communities.

5. Multi-disciplinary research in Asia and Latin America: contributions to a central African SBE research agenda

In South Asia, Southeast Asia, and Latin America, where SBE also imposes a high burden, a multi-disciplinary snakebite literature can offer guidance for research and action in central Africa (Kasturiratne et al., 2008). As in central Africa, South and Southeast Asian and Latin American populations most afflicted by SBE live in rural areas, and undertake agricultural, cattle raising, hunter-gathering activities (Ediriweera et al., 2019; Feitosa et al., 2015; Jayawardana et al., 2020). Anthropological tools and analyses are not as well integrated into the SBE literature as they could be, but nevertheless, some qualitative methodologies have effectively shed light on human-snake encounters and particularly local healing practices.

Research in South and southeast Asia and Latin America has explained SBE in terms of biodiversity loss and seasonal changes (Chaves et al., 2015; Jayawardana et al., 2020; Monteiro et al., 2020); human-induced ecological changes that provide easy shelter and prey for venomous snakes (Atreya and Kanchan, 2018; Monteiro et al., 2020); negative human attitudes toward snakes (Pandey et al., 2016); as well as certain religious practices. In Nepal and India, for instance, Hindu religious practices are strongly associated with very high snakebite burden (Kumar, 2006). There, rural populations worship cobras ('*nag-deva*' deity) in shrines, roadside temples, and water sources to counter infertility, ill fortune, or curses, to prevent snakebites, and to ensure the water supply (Atreya and Kanchan, 2018; Kumar, 2006). Snakes are hunted and used for Ayurvedic and traditional medicines, and snake charmers use them to gain their livelihoods (Atreya and Kanchan, 2018). Another example involves Baniwa people of the Brazilian Amazon and their complex relations with fish and snakes. Baniwa people contend that fish are descendants of the great snakes; both fish and snakes are at once enemies of humanity (*walimani*), but people also depend on them for food. In one narrative, *Niāpirikoli*, the creator god, and his relatives fight with snakes, killing them or expelling them from the lakes to provide space for humans. Whereas defeating snakes facilitates human access to fishing sites, it simultaneously reduces fishes' capacity to reproduce (Garnelo, 2007).

High-risk regions of Asia and Latin America share some of the very same barriers to treatment for SBE as in Central Africa: long distances to health centers, insufficient numbers of hospitals, poor training of health workers, inaccessibility or underdosage of AV (da Silva Souza et al., 2018; Inthanomchanh et al., 2017; Monteiro et al., 2020; Sapkota et al., 2020; Williams et al., 2017).

SBE literatures in Asia and Latin America have integrated qualitative methodologies to document local remedies to extract venom or to prevent its spread (Barros et al., 2012; da Silva et al., 2019; Dharmadasa et al., 2016; Giovannini and Howes, 2017; Oliveira et al., 2013; Sapkota et al., 2020). One study examined wide-ranging healing practices of SBE victims among Amazonian indigenous peoples; such practices sought not only to treat the multifarious effects of venom on the integrity of victims' body as well as on their kin and other social relations (Monteiro et al., 2020). In multiple settings, commentators have recommended training and integration of traditional healers in first aid and referral to appropriate healthcare structures (Anwar et al., 2012; Kularatne et al., 2014; Schioldann et al., 2018).

Although not well-investigated, SBE imposes considerable financial burdens on victims' households (Hasan et al., 2012; Kasturiratne et al., 2017), and has long-term physical and psychological consequences for survivors' health and capacity to work (Arias-Rodríguez and Gutiérrez, 2020; Jayawardana et al., 2020; Williams et al., 2011).

Table 1
Anthropological questions and methods for snakebites in central Africa.

Research question	Methods to be used	Potential contribution
What snakes live in a specific site and what local ecological knowledge exists of these snakes?	Ethno-biological methods, interviews and participant-observation	Local ecological knowledge of snakes
What frequency of contact do people have with snakes? What type of contact? And what activities are people conducting during those contacts?	Participatory activity and contact evaluation	Real-time tracking of specific types of contacts, activities, and frequencies of contacts with different snake species
What local ecological, ethnohistorical, and socio-cultural knowledge exists of snakes? What are the most common practices to treat snakebite envenomation?	Photovoice	Local anthropological and ethnohistorical understandings of snakes and their ecological niches; snakebite treatments and preferences for care
How and why do local healers treat snakebites? Why do those bitten by snakes prefer to consult local healers? What are the outcomes of SBE treatments provided by healers? What outcomes of treatments by local or regional health structures? How would healers and local populations perceive and seek access to AVs if these treatments were readily available and offered for low cost or free-of-charge?	Participant-observation of formal health care structures; interviews with patients, healers involved in snakebite treatment Collection and analysis of treatment outcomes among healers and health structures	Practices and local preferences for SBE treatment; integration of local knowledge and practices into formal health care system; perspectives on outcomes for regional and national health authorities

6. Multidisciplinary and participatory approaches to SBE in Central Africa

In central Africa, where to our knowledge there is little public health-oriented anthropological research on SBE, multi-disciplinary approaches that bring together anthropology, history and ecology in participatory research-action could deepen insights into the specific dynamics of human-snake interactions and care-seeking after SBE and contribute to adapted healthcare initiatives to tackle this problem. Given the historical, socio-cultural significance of snakes across central African societies, efforts to prevent and care for SBE will achieve greater effectiveness if they integrate local understandings of snakes and snakebite events and work collaboratively with local populations, leaders, and regional and national authorities to develop feasible interventions and care.

Anthropological approaches use multiple methods, including semi-structured interviews, focus groups and textual analysis to develop an internal understanding of the worlds that an individual and social group inhabit (Bernard, 2017). Participant-observation also is a key methodology in anthropological research, enabling the researcher to participate in daily practices over time and to forge relations with informants. Ultimately participant-observation can help to develop insight into how people act in and conceptualize their worlds, the linkages between different domains of life (for instance, health, economy and religion), the exercise of power in these moments, local healing knowledge and practice, health-seeking behaviors, and biomedical care (Lock and Nguyen, 2018; Pool and Geissler, 2005).

Using these approaches, more systematic collection and analysis of anthropological evidence on snake encounters and envenoming (i.e.

human-snake interactions, context of the bite, types of human activities, shared ecologies, human and snake behavior after the encounter, local histories, myths, and perceptions) would thus assist in: (1) identifying new risk factors that epidemiological investigations may overlook, (2) offering a deeper understanding of the modalities (contexts, locations, timing) of human-snake contacts, (3) understanding in greater depth local unwillingness to seek biomedical care rapidly, and (4) providing insight into the social and psychological place of local healers and healing for snakebites, so as to develop adapted and more effective interventions. The following participatory ecological and anthropological approaches could integrate local knowledge into snakebite prevention and care in central Africa (Table 1).

6.1. Participatory ethno-herpetology

Ethno-herpetology, a subfield of ethnobiology, describes relations between humans and snakes; their historical, economic, anthropological and environmental dimensions; practices and knowledge about snakes; the vernacular names and categories of snakes, as well as their historical, symbolic and utilitarian values (Alves and Souto, 2015). Using multiple methods, from qualitative interviews to quantitative surveys (Albuquerque, da Cunha, De Lucena and Alves, 2014), an ethnobiological investigation could collect narratives about snakes, bites and human-snake encounter in specific environments. Because snake identification is crucial to optimize clinical management, this investigation could also document the abilities of local people and healers to identify snake species and trace how identification affects therapeutic itineraries (Bolon et al., 2020). Although ethnozoological studies often seek to improve conservation efforts by integrating local perspectives on animals (Alves, 2012), they could be reconfigured as participatory investigations that integrate two-way instruction between researchers and people living in proximity to snakes. Such investigations could also provide foundations for developing adapted public health strategies.

6.2. Contact frequency studies

A better understanding of SBE in equatorial Africa also requires deeper insight into the diversity of human-snake encounters, upstream of biting situations. One innovative participatory method would measure contact frequencies, types of human-snake interactions and shared habitats by collaborating with local people living in proximity to snakes. Integrating local inhabitants into the research process to record encounters with snakes. This approach draws from research protocols that Romain Duda and Tamara Giles-Vernick have implemented in the Democratic Republic of Congo, and that Tamara Giles-Vernick's research team has put into place in Cameroon (Narat et al., 2018).

Implementing this study among multiple populations residing in different ecological and subsistence settings (forested, deforested, forest-savanna mosaic, economy dominated by swidden agriculture, fishing, hunting/gathering) would refine risk profiles and practices. Participant-volunteers would document each encounter with a snake over a pre-determined time frame. Each noted encounter would include contextual information, including the time, location, ecological habitat, activity pursued by the participant at the time of contact (visual or physical), vernacular name of the snake, behavior adopted by the participant, observed behavior of the snake, whether the participant was bitten, treatment received, whether the participant killed the snake, precautions taken, weapon used, and the fate of the dead snake (consumed or not). This investigation would yield a detailed tracking of snakebites among our participant-volunteers. In contrast to a strictly epidemiological approach, which would count only snakebites, our participatory approach situates all interactions between people participating in the study and snakes into their broad contexts. By contextualizing all contacts (including but not limited to bites), we would derive more detailed insight into how and why human beings and snakes come into engagement in a specific site.

6.3. Photovoice

Recommended by the WHO, photographing snakes is already an emerging practice in public health initiatives in many countries (WHO, 2010). It permits better identification of biting species for health workers and improves clinical management, notably where AVs are rare (Bolon et al., 2020). Extending the participatory, bottom-up nature of photography, *photovoice* is a participatory methodology that engages a group to collect and evaluate photographic and narrative evidence, and potentially to identify appropriate solutions to a problem. It has been used to great effect in wide-ranging situations (Iskander, 2015), and Tamara Giles-Vernick has employed it with adolescents in Antananarivo, Madagascar. The photovoice methodology gives simple, low-cost cameras to a small group of participants, as well as GPS trackers. Participants are trained to take photos and to use the GPS. They meet regularly with a facilitator, who frames certain questions and asks the participants to take photos in response to that question, to mark with the GPS locations where a photo is taken (forest paths, abandoned fields, villages), and to provide a narrative about the photo itself. An initial, broad question pertaining to snakebite in the central African forest might be, "What do snakes in my community mean to me?" Over several meetings, as participants improve their photography skills, engage in discussions, the questions that the facilitator poses will be increasingly precise. The facilitator guides the participants in an analysis of the photos and in an identification of specific measures in response to the problem.

This participatory approach, when applied to health issues as well as human-animal contacts, can reveal local, fine-grained understandings of ecologies, avoidance practices, symbolic meanings of snakes, as well as benefits and limitations of specific care practices. In facilitating local participants' analyses of the photos and associated narratives, the photovoice method creates useful knowledge and can elucidate local priorities and assist in the development of adapted SBE interventions to improve quality of life (Foster-Fishman et al., 2005).

6.4. Investigation of formal health structures and systems, local healing practices for SBE, and their integration into improved care

Observation of snakebite treatment at formal health structures as well as interviews with healers, snakebite patients, formal health workers, and regional and national authorities can provide rich anthropological and policy insight into treatment practices, preferences for local healers, and local perceptions and acceptance of antivenom treatments. These insights can and should provide the grounds for improved management. Because forest inhabitants often seek care for snakebites from local healers, encouraging changes in SBE care-seeking practices may not be easy. Preferences for traditional medicine, as well as limited access to and low consultation of rural health structures may constitute barriers to antivenom use, even if such treatments were made available at low cost. Ensuring production of and access to antivenom treatments thus cannot be done in isolation; it must be accompanied with socially and culturally adaptive outreach that integrates local knowledge of snakes and SBE and fully engages community health actors, including traditional healers. Local healers are key care providers for those sustaining snakebites and should not be excluded from efforts to strengthen treatment and prevention of SBE (Schioldann et al., 2018; Tianyi et al., 2018). Regional-level health workers could assist in identifying local healers specializing in snakebites. Collaboration between formal health structures and local healers could enhance prevention efforts and integrate healers' expertise in assuaging patients' anguish and redressing social and spiritual conflict.

7. Conclusion

Multi-disciplinary snakebite investigation that integrates anthropological and ethnohistorical research has not, to our knowledge, been a

Table 2

Major findings and recommendations.

- Central African forests are a hotspot for snakebite envenomation.
- Research on SBE in central Africa has not mobilized a rich historical or anthropological literatures, tools, or methodologies.
- Participatory anthropological and ethnohistorical investigation should be integrated with ecological data to identify:
 - significance of snakes and snakebites
 - types and frequencies of contacts with snakes evaluated alongside activities
 - local diagnostic and treatment practices to understand preferences for local healers over formal health structures.
- Policies and practices to reduce SBE burden in central Africa should also build on participatory anthropological and ethnohistorical research.
- Policies and practices to reduce morbidity and mortality from SBE should be co-developed with local forest communities and leaders and regional and national authorities.

priority for SBE research and action in central Africa. We would argue, however, that expanding multi-disciplinary, participatory approaches to account for the ecological, historical, and anthropological significance of snakes, to trace the frequencies and contexts of human-snake contact and the social importance of snakebites, and to provide fine-grained documentation of local diagnostic and treatment options could make significant contributions to the community and multi-scale engagement that the WHO SBE roadmap advocates. This approach would involve close collaborative research, intervention development and implementation with central African forest inhabitants, healers, health care workers and leaders. It would yield, we contend, better adapted and more responsive policies and practices to prevent and treat SBE (Table 2).

Credit author statement

RD and TG-V conceptualized the piece and wrote an initial draft. WM wrote sections of the draft pertaining to SBE outside of central Africa. All authors reviewed and edited the manuscript.

Ethical statement

The data collected for this manuscript has already been published and respected all relevant national and international ethical standards governing the conduct of research with human subjects.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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