



Snakebite envenoming from an Ecohealth perspective

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ARTICLE INFO

Keywords:

Snakebite envenoming
Ecohealth
One health
Trans-disciplinary research

ABSTRACT

Snakebite envenomings occur in complex ecological, social, economic, cultural, and political contexts. Hence, the understanding of this public health issue demands systemic and holistic approaches. Ecohealth constitutes a valuable paradigm to study snakebites, as it emphasizes on the close linkages between ecosystems, society, and health. This essay highlights some of the areas in the field of snakebite envenoming that could greatly benefit from an Ecohealth approach based on trans-disciplinary research, systems thinking, and the involvement of stakeholders at many levels. Ecohealth focuses not only on the generation of knowledge through research, but also in the translation of knowledge into actions.

1. Introduction

Diseases occur in specific ecological, social, economic, cultural, and political contexts. Therefore, a proper understanding of any disease and its implications on the wellbeing of humans and animals demands integrated efforts involving diverse disciplines and stakeholders. Such holistic, systemic perspective is necessary to fully grasp the complex and non-linear nature of health issues. Hence, the traditional reductionist, strictly biomedical approach to study diseases should be complemented by inter- and trans-disciplinary efforts within a broader scope.

The last decades have witnessed the emergence of new fields having such comprehensive view in health sciences. An example is One Health, which brings together the expertise of human and veterinary medicine in the study of health issues, focusing on the interface of humans and domestic animals in specific social and ecological contexts. One Health provides an added value based on the cooperation between human and animal health disciplines, with the consequent impact on practical interventions based on this integration (Zinsstag et al., 2015). Some of the foundations of the One Health concept were established in the so-called Manhattan Principles, after a meeting held in 2004 (Cook et al., 2004). A related, albeit broader approach centers in the concept of Ecohealth, a systemic and trans-disciplinary field of research, education, and practice that considers the close linkages between ecosystems, society, and health. Ecohealth brings an ecosystem approach to understand health issues by incorporating multiple types of knowledge from natural and social sciences, and the humanities, with the involvement of stakeholders at many levels within a participatory research frame (Charron, 2012a, 2012b; Zinsstag, 2012).

As many other diseases, snakebite envenoming can be viewed from these holistic, integrated perspectives, in order to grasp its complexity and to provide knowledge and solutions for reducing its impact. The WHO strategy for the control and prevention of snakebite envenomings provides a valuable framework with a holistic focus, which needs to be further enriched (WHO, 2019). A call to view snakebites from a One Health perspective has been made (Martins et al., 2019), and efforts are underway to include the veterinary aspect in the analysis of these envenomings (Bolon et al., 2019). Efforts in research and public health interventions to reduce the impact of snakebite envenomings should promote these integrated frames. The following sections highlight some issues of snakebites viewed from the Ecohealth perspective, and underscore areas that require attention by research groups, communities and policy makers.

2. Impact of environmental changes in the populations and distribution of snakes

Snakebite envenomings in humans and domestic animals occur in contexts where human populations, especially those engaged in agricultural and pastoral activities, and livestock enter in contact with venomous snakes, either by invading snakes habitats or because these reptiles adapt to environments altered by human activities. In this sense, the study of the relationship between snake and human populations is relevant and allows the identification of 'hotspots' for snakebites (Longbottom et al., 2018). Snake populations are affected by many factors, such as habitat destruction, reductions or increments in the populations of prey, changes in climate variables, and use of

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<https://doi.org/10.1016/j.toxcx.2020.100043>

Received 2 May 2020; Received in revised form 16 May 2020; Accepted 20 May 2020

Available online 23 May 2020

2590-1710/© 2020 The Author(s).

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agrochemicals, among other issues. There is consistent evidence of decline in vertebrate populations in the world, including reptiles (Gibbons et al., 2000; Winne et al., 2007). For example, a study of 17 snake populations from 8 species revealed a rapid decline in many of them over a relatively short period of time, whereas only one of them showed a slight increment (Reading et al., 2010). It is relevant to assess variations in snake populations secondary to anthropic environmental alterations. A study in Brazil documented an expansion in the distribution range of the rattlesnake *Crotalus durissus terrificus*, whereby this species invaded new deforested patches turned into grazing areas (Bastos et al., 2005). In Costa Rica, *Bothrops asper* adapts well to areas where forests turned into agricultural or cattle raising activities (Sasa et al., 2009). On the other hand, the populations of many snake species drop because of primary forest alteration. The impact of the change in land use on the incidence of snakebites is an area that demands understanding, and the information of agricultural censuses, *vis-à-vis* the data on incidence of snakebites, provides valuable information.

The reasons behind such decline in snake populations are likely to be multifactorial and may be related to pollution, loss of habitats, drops in the populations of prey, diseases, overexploitation, and climate change, among others. A recent study revealed a drastic collapse in a neotropical snake community associated with the massive loss of amphibians due to infections by the fungal pathogen *Batrachochytrium dendrobatidis* (Zipkin et al., 2020). Noteworthy, unique variations were described in different snake species, probably related to diet or to differences in the ecological plasticity to cope with environmental changes. Access to prey affected microhabitat selection and patterns of movement in *Bothrops asper* (Wasko and Sasa, 2012), which in turn may influence the likelihood of contacts of snakes with humans. Hence, despite a general trend of species decline due to environmental alterations, differences exist between species. These issues illustrate the relevance of studies on the natural history and ecology of snakes for understanding the causal complexity of this scenario (Murray et al., 2020), a task that would greatly benefit from a systemic approach. From the Ecohealth perspective, the study of natural history should involve not only specialists, but also contributions from people in the communities, in the frame of 'citizen science' (Ruiz de Castañeda et al., 2019). A growing number of groups are currently sharing information on snake distribution and snakebite occurrence through social networks, generating a valuable body of evidence.

A topic that has received little attention is the impact of environmental pollution on snakes and snakebites. The growing use of agrochemicals and pesticides has an impact on these reptiles (Rainwater et al., 2005), and they can be used as bioindicators of contamination in environments (Lettoof et al., 2020). There are intricate relationships between human, domestic animal, and wildlife health, which can be studied within the Ecohealth paradigm. On one hand, the use of agrochemicals influences the health and distribution of snakes and affects their prey. In addition, the effects of such substances in humans and domestic animals may influence the severity of snakebite envenomings, as occurs regarding renal effects after snakebites in agricultural workers exposed to agrochemicals (Silva et al., 2014). This calls for the study of physical and psychological comorbidities, some of which are associated with environmental degradation, in the severity of envenoming. The overall impact of the extensive use of environmental toxicants in the distribution of snakes, as well as in the incidence and clinical manifestations of envenomings, is an open field of research.

3. Effect of global climate change

Climate changes, including global warming, impact in many ways on the interactions between humans, snakes, domestic animals, and ecosystems. The projections on the impacts of global warming in ectotherms, including vertebrates, have been described, with an ongoing risk of extinctions (Sinervo et al., 2010). It is likely that the extinction risks owing to global warming are higher in the tropics (Deutsch et al., 2008), where most venomous snakes are distributed. The rise in temperature

also influences the distribution range of snakes, with the consequent impact on the increased or decreased risk of snakebite envenoming. Several models have been used to predict future distribution variations, as determined by a set of climatic and other environmental factors (Franklin, 2009). Species Distribution Models (SDMs) and Ecological Niche Modeling (ENM) are useful tools to study distributional patterns of species and to predict variations caused by changing environmental and climatic conditions (Franklin, 2009; Yañez-Arenas et al., 2014). These tools establish correlations between the occurrence of a species and environmental variables so that models can be projected into hypothetical future climate conditions. Examples of studies using these models for predicting the future distribution of snake species are those of Nori et al. (2014), Sahlean et al. (2014), Yañez-Arenas et al. (2016), and Terribili et al. (2018). It has been proposed that, in Latin America, there will be an expansion of the overall risk area for snakebites and an increase in the rural population at risk for these accidents (Yañez-Arenas et al., 2016). However, it is likely that variations will occur between snake species in such a way that the individual contribution of species to the overall snakebite burden will differ. Noteworthy, some of these analyses rely mostly on abiotic factors for the predictions (temperature, humidity, radiation). However, biotic variables need to be also considered, such as changes in predators, prey, possible diseases, and plant dynamics. This illustrates the complexity of these phenomena and the need to further expand the variables involved.

An association was described between the incidence of snakebites in Costa Rica and the climatic phenomenon of El Niño (Chaves et al., 2015). The reasons behind this are not clear but are likely to depend on changes in prey availability and in the range of distribution of snakes. The increment in natural disasters associated with climate change also influences snakes and snakebites. An increased incidence of snakebites has been described in Asia because of the monsoon (Alirol et al., 2010), and in the coastal region of Ecuador due to flooding (Tauzer et al., 2019). In such situations, there is not only an increased incidence of snakebites, but also the management of these accidents turns more complex owing to difficulties in transportation, damage to health facilities, and deficits of health personnel to attend the various emergencies resulting from these socio-natural phenomena. Hence, the analysis of changes in the distribution and population density of venomous snakes at the local and regional levels owing to climate change must be studied in order to identify emerging trends that may influence the incidence of envenomings.

4. Snakebite at the interface between human and veterinary medicine in the context of ecosystems

The One Health concept allows the understanding of snakebite envenoming from a broad perspective at the interface between humans, domestic animals, and agroecosystems (Martins et al., 2019), and has close connections to the concept of Ecohealth (Zinsstag, 2012; Zinsstag et al., 2015). The One Health approach provides bridges between the previously separated fields of human and veterinary medicine, and the Ecohealth view incorporates the study of ecosystems alterations in this scenario. The impact of snakebite envenomings in domestic animals has been a rather neglected field of study. Fortunately, the interest in this subject is growing (see Bolon et al., 2019), and studies on envenomings in animals are more frequent in the literature. The picture that is emerging underscores the high impact of snakebites in livestock, and their consequent social and economic effects. In Costa Rica, for example, envenomings by *Bothrops asper* cause a heavy toll in cattle (Herrera et al., 2017), and probably a similar situation occurs in other countries. It is relevant to assess how environmental changes modify the distribution of snakes and influence the likelihood of contacts between these reptiles and domestic animals.

Since snakebites mostly affect impoverished rural populations, the loss of livestock due to envenomings further deepens these populations into a vicious cycle of poverty. The veterinary interventions related to

envenomings deserve renewed consideration. Antivenoms for veterinary use are available in few countries (Rodríguez et al., 2016), and the treatment of these envenomings in animals often rely on symptomatic management and, in many cases, on ineffective and often harmful interventions. In Costa Rica, an active immunization based on the administration of a toxoid is under development, and passive immunization with antivenoms is also available (Herrera et al., 2017). Another impact of snakebites in the relation between humans and livestock is that often people need to sell animals to pay the costs of treatment of snakebites (Vaiyapuri et al., 2013). It is necessary to develop research in the field of snakebites in domestic animals and their implications in rural agroecological contexts. Moreover, the ways in which alterations in ecosystems affect the incidence of snakebites in humans and domestic animals need to be understood. An ambitious project is being developed in Nepal and Cameroon to document the effects of snakebites in livestock (Martins et al., 2019). Another aspect that deserves to be investigated is the impact of snakebites in dogs, cats and other pets, and their effects in human welfare.

5. Snakebites and the many faces of poverty

The Ecohealth paradigm places emphasis on the social determinants of health and the issue of equity, two concepts that have received international attention and bear ethical implications (Sen, 2004; Marmot, 2015). Environmental problems are intricately linked to inequity, and impoverished populations often live in degraded environments that, in turn, are harmful to their health in many ways (Charron, 2012a). This is relevant for snakebite envenoming since it is considered a 'disease of poverty', as it mostly affects people living in impoverished rural communities of sub-Saharan Africa, Asia, Latin America, and parts of Oceania (Harrison et al., 2009; Chaves et al., 2015; Gutiérrez et al., 2017). Moreover, the consequences of envenomings further expand the poverty conditions of affected people. The Millennium Development Goals (United Nations, 2000) and the Sustainable Development Goals (United Nations, 2015) aim at significantly reducing poverty on a global basis, under the motto 'leave no one behind'; however, we are far from achieving these objectives. The current COVID-19 pandemic is having a drastic impact in the living conditions of millions of people, with a huge increment in the number of those living in poverty. Beyond the general concept that snakebites largely impact in the global poor, it is necessary to further understand specific aspects of this relationship. In these efforts, the participatory nature of the research is essential, i.e. the involvement of affected people at the community level in knowledge generation and application (Charron, 2012b). Examples of areas that require research, understanding, and actions are:

5.1. What is the impact of envenomings in different impoverished settings?

The complex interrelations between ecological, economic, social, cultural, and political conditions that characterize impoverished populations demand specific analyses at the local level.

Such a systemic approach fits within the rationale of Ecohealth. For instance, the conditions differ between agricultural and pastoral groups, or between populations that have access to government and civil society programs and those which lack such support. Likewise, the circumstances vary between communities characterized by self-reliance in food supply and those in which people are employed by large agroindustrial complexes. The relationships between physical characteristics of houses, poverty condition, and the likelihood of the presence of snakes nearby residences must be investigated in the context of ecosystems. Moreover, from an Ecohealth perspective, it is relevant to assess how environmental degradation impacts on the consequences of snakebites in impoverished settings. This will allow the implementation of knowledge-based interventions tailored to particular settings.

5.2. How do snakebite envenomings affect different ethnic groups?

The regions where most snakebites occur are characterized by a multicultural and multiethnic richness, in the context of variable degrees of environmental degradation in ecosystems.

In many locations, specific ethnic groups suffer structural discrimination, exclusion, and inequity, with the consequent implications in diverse aspects of life, including physical and mental health. Many of these populations have higher levels of poverty as compared to the rest of their countries. In Latin America, indigenous groups account for about 17% of people living in poverty in this part of the world, while representing only 8% of the total population (PAHO, 2017). There is evidence that snakebites greatly affect such indigenous communities (Pierini et al., 1996; da Silva Souza et al., 2018). Many of these groups have limited access to health services, hence complicating the treatment of envenomings. Likewise, many of them are threatened by the destruction of the environments where they live. Owing to the great diversity of ethnic groups in sub-Saharan Africa, Asia, and Latin America in areas of high incidence of snakebites, differentiated approaches are required to study envenomings and their determinants within a frame of multiculturalism. This demands renewed trans-disciplinary research efforts, with the active engagement of these communities.

5.5. How do snakebites affect migrant populations?

According to the International Organization for Migration (IOM), in the year 2015 there were 244 million international migrants, representing approximately 3.3% of the total world population (IOM, 2018). Among other regions, a significant migratory process has taken place in Central America, where 10–12% of the total population has migrated due to social and economic exclusion in their countries (Sandoval-García, 2017). Likewise, large-scale migrations are taking place in Africa and the Middle East. Among many causes, migrations are related to environmental degradation linked to global climate change and other factors. A large portion of global migrations occurs between countries of the South (Sandoval-García, 2017), i.e., those most affected by snakebites. Among other aspects, migrant and refugee populations suffer health problems of many sorts (for the case of Africa, see WHO, 2018a). Besides international migration, the phenomenon of internal migration is also relevant in many countries. In Colombia, for example, several million people, mostly from the rural areas, have been displaced over the past decades due to the internal armed conflict (Gómez Builes et al., 2008). Amidst the many perils that migrants suffer in various parts of the world, snakebites constitute a permanent risk yet to be investigated. Migrants often do not have access to health services, hence increasing the severity of these accidents. The paths followed by migrant populations are often affected by degradation of ecosystems, with multiple consequences for the people. The effects of snakebites in migrants deserve attention by researchers, governments, advocacy groups, and local communities.

5.4. How do the sequelae of snakebites have a differential impact in vulnerable people?

Snakebite envenomings often result in the development of permanent physical and psychological sequelae which greatly hamper the quality of life of affected people (Williams et al., 2011; Gutiérrez et al., 2017; Waiddyanatha et al., 2019).

People living in poverty who suffer these sequelae are often left unattended by governments and civil society organizations. Even in countries where patients receive antivenom treatment free of charge, such as Costa Rica, a qualitative study revealed that informal agricultural workers, or people working on their own, do not get rehabilitation or compensation after snakebites (Arias-Rodríguez and Gutiérrez, 2020). The WHO strategy to prevent and control snakebite envenomings stresses the need to develop interventions that support these people and

compensate for the consequences of envenomings (WHO, 2019). This calls for concerted research efforts to document the extent of the problem in different settings and to search for solutions, along the Ecohealth goal of putting knowledge into action through policy change and interventions (Charron, 2012b).

5.5. Snakebite envenomings from a gender perspective

Snakebites exert a heavy toll on women and girls. Yet, there has been scarce interest in the study of this health problem from a gender perspective. Depending on the ecological, cultural, social, and economic conditions, snakebites may affect women and girls in different ways as compared to men. Bites in women who are heads of households have a drastic impact on whole families since they affect the possibility of working outside and inside the home, contributing to poverty and affecting the care of children and elders. Moreover, depending on the cultural contexts, the stigma resultant from physical and psychological sequelae after envenomings affects social interactions and family life in women and girls. In addition, in some settings it is harder for women than men to reach health facilities, hence affecting the prognosis of envenomings. In relation to migration, almost half of all African migrants are women, and this poses significant challenges in health (WHO, 2018b). The study of snakebite envenoming from a gender viewpoint, integrating the ecosystem perspective, may reveal unique aspects that require attention and specific interventions.

6. Towards a 'dialogue of knowledges': the need for participatory approaches

The holistic approach of Ecohealth involves not only the participation of researchers from a variety of disciplines, within a frame of 'epistemic respect' and trans-disciplinarity, but also the involvement of many stakeholders in the generation of knowledge and its translation into practical applications. From this perspective, the active engagement of communities and people affected by snakebites is essential, through participatory research and implementation of interventions tailored to the local cultural and ecological contexts and needs. In other words, the scientific community, international foundations, non-governmental organizations, health agencies, and governments should be in permanent dialogue with the knowledge and initiatives emerging from the local settings where snakebites occur, within a frame of participatory research. The role of civil society organizations in public health is steadily growing and needs to be consolidated (Greer et al., 2017). Thus, the merging of top-down and bottom-up approaches should be fostered in the context of a 'dialogue of knowledges'. This is compatible with the first pillar of the WHO strategy for snakebite envenomings, i.e., 'empower and engage communities' (WHO, 2019). Trans-disciplinary research, with the active participation of social sciences and social actors, and the creation of dynamic networks, is required to achieve these goals. This involves a shift in our traditional views on how knowledge is generated, transmitted, and applied.

7. Challenges for the field of toxinology

The community of toxinologists working on snake venoms and snakebites can greatly benefit from Ecohealth's integrated perspective. Venoms and toxins of natural origin, the centerpiece of toxinology, can be studied holistically, considering their roles in ecosystems, human and veterinary health, and social, economic, and cultural settings. This calls for the understanding of venoms and toxins in their ecological contexts, which urges a close interaction between toxinologists and ecologists. The -omics methodologies, by providing a rich body of knowledge, offer enormous possibilities to grasp this complexity. Likewise, the study of venoms and venomous species should be linked to the impacts of envenomings in humans and animals, and to the search of improved therapies and more effective public health interventions. Envenomings

should be viewed considering the social, economic, and cultural coordinates of the communities where they occur. As discussed, understanding the various aspects of venomous species, and their interrelations with humans and ecosystems, demand participatory research involving the local communities.

These challenges urge innovations in the way toxinological research is carried out, communicated, and translated into effective actions. Trans-disciplinary groups, incorporating the ecosystem and social views, should be promoted at universities and other research institutions, and supported by funding agencies. Likewise, these integrated perspectives must be fostered by academic gatherings and journals. The International Association for Ecology and Health was created in 2006, and the journal EcoHealth promotes this trans-disciplinary field. Specialized journals in toxinology, proteomics, herpetology, and related topics may stimulate contributions or publish special issues on Ecohealth and snakebites. There are plenty of challenges for researchers in toxinology, herpetology, tropical medicine, public health, and other fields to incorporate the paradigm of Ecohealth in their academic and social pursuits.

8. Final remarks

The concepts of Ecohealth, and its closely related field of One Health, provide integrated, systemic, and multi-causal paradigms to analyze the complexity of health issues. Ecohealth brings an ecosystem approach to study health. It is characterized by systems thinking, trans-disciplinarity, participation, sustainability, search for social and gender equity, and transformation of knowledge into action (Charron, 2012). In this essay, I have argued that Ecohealth allows for a comprehensive view of the multiple angles of snakebite envenomings. It provides not only a deeper and holistic understanding of phenomena, but also tools for the design and implementation of interventions aimed at reducing the impact of this neglected tropical disease, within the general purpose of improving the conditions of humans, animals and ecosystems. Working within this paradigm in the snakebite field demands efforts to create trans-disciplinary research teams that include natural as well as social sciences, technologies, and the humanities. It also calls for active participation of communities and organizations of the civil society, in addition to many other stakeholders, for the full implementation of the WHO strategy to prevent and control snakebite envenomings. These concerted efforts should stand on the ethical pursuit for equity and for improving the quality of life, while fostering the sustainability of ecosystems.

Ethical statement

This manuscript was prepared following internationally accepted ethical guidelines for the preparation of scientific papers.

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.

Acknowledgements

Thanks are due to Luis Fernando Chaves, Ana Cecilia Escalante, Rafael Ruiz de Castañeda, Carlos Sandoval, Juan J. Calvete, and Mahmood Sasa for providing valuable insights on these topics.

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