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Living with wolves: Lessons learned from Iran

Alireza Mohammadi[1] | **Amir Alambeigi**[2] | **José Vicente López-Bao**[3] | **Lobat Taghavi**[4] | **Mohammad Kaboli**[5]

[1]Department of Environmental Science and Engineering, Faculty of Natural Resources, University of Jiroft, Jiroft, Iran

[2]Department of Agricultural Extension and Education, College of Agricultural Economics and Development, University of Tehran, Karaj, Iran

[3]Research Unit of Biodiversity (UO/CSIC/PA), Oviedo University, Mieres, Spain

[4]Department of Environmental Science, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran

[5]Department of Environmental Science, Faculty of Natural Resources, University of Tehran, Karaj, Iran

Correspondence
Mohammad Kaboli, Department of Environmental Science, Faculty of Natural Resources, University of Tehran, Karaj, Iran.
Email: mkaboli@ut.ac.ir

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Abstract

Given the complex and dynamic interrelationships of the underlying factors contributing to conflicts associated with wolf presence and persistence in human-dominated landscapes, it is often difficult to clearly identify the ultimate causes of these conflicts. In this study, a system dynamics modeling approach was adopted to simulate human–wolf conflicts in an area with the greatest number of recently fatal wolf attacks on humans in Iran. Data used to build the model were obtained from questionnaire surveys and satellite tracking of wolves. We simulated changes in ecological and social factors that may influence conflicts under different assumptions. Our findings indicate that, in this context, the proximity of wolves to human settlements is one of the determining factors leading to increased wolf attacks on humans and livestock. When the distance between wolf territories and human settlements increases, the likelihood of both wolf incidents and retaliatory killings are expected to decrease. Effective communication of information regarding wolves across local communities is expected to result in a positive shift in attitudes toward the species, as well as a decrease in fear, which in turn will affect the rate of conflicts. Improper disposal of carcasses of domestic animals by the locals, dumping of waste in open dumpsites close to villages, and leaving children unattended on agricultural fields are expected to increase the recurrence of conflicts. We strongly urge Hamadan provincial office of environment and nongovernmental organizations to initiate communication programs to raise awareness on the human–wolf conflict and its mitigation. This includes how to properly handle livestock carcasses at safe distances from human settlements. Furthermore, design and construction of sanitary landfills in the vicinity of each village, as well as providing education on how to properly use these sites could help reduce risky conflicts.

KEYWORDS

coexistence, Hamadan province, human–wolf conflicts, Iran, social and ecological factors, system dynamics, wolf incidents

1 | INTRODUCTION

The persistence of large carnivores in human-dominated landscapes represents a formidable conservation challenge as a result of real or perceived impacts on humans and their livelihoods. Multiple conflicts surround the presence of large carnivores in these scenarios, and different conflict drivers have been identified, including the predatory behavior of large carnivores, fear of carnivores or risks posed by these species to human safety (e.g., Löe & Röskaft, 2004; López-Bao et al., 2017; Lute et al., 2018; Mohammadi, Alambeigi, et al., 2021).

The gray wolf (*Canis lupus*) is a well-known opportunistic carnivore and a facultative scavenger, capable of relying on different anthropogenic food items, such as livestock and garbage (Mech & Boitani, 2010; Mohammadi et al., 2019; Newsome et al., 2016); increasing their likelihood of persisting in highly human-dominated landscapes (e.g., Kuijper et al., 2019; Mohammadi, Lunnon, et al., 2021). In some areas, anthropogenic food sources constitute the primary diet of wolves, allowing them to live in areas with low abundance of wild prey (Ciucci et al., 2020; Mohammadi et al., 2019; Newsome et al., 2016). However, wild prey abundance is not the only factor contributing to dependence of wolves on anthropogenic food sources (Hosseini-Zavarei et al., 2013; Kikvidze & Tevzadze, 2015; Mohammadi et al., 2022). Many conflict scenarios are associated with livestock or pet depredations or a perceived competition for game (Hosseini-Zavarei et al., 2013; Suryawanshi et al., 2013; Trbojević et al., 2020).

Yet, in scenarios with reports of wolf attacks on people, effective management is more complicated. For instance, in a human-dominated landscape in Asia, low availability of wild prey, coupled with ineffective management of organic waste management, has led to increased human–wolf conflicts, particularly attacks on people (Behdarvand & Kaboli, 2015; Mohammadi et al., 2017, 2019; Mohammadi, Lunnon, et al., 2021). In these scenarios, top priority must be assigned to understanding the mechanisms underlying the occurrence of risky situations.

Conflict scenarios can persist even after the implementation of damage prevention measures (Eklund et al., 2017) or reduction of damage (e.g., Bruns et al., 2020; Khorozyan & Waltert, 2019a, 2019b). Most studies addressing human–wolf conflicts have focused on the technical aspects of conflict reduction (Bruns et al., 2020; Stone et al., 2017). It appears human–wolf conflicts arise within the context of a complicated social-ecological network under the influence of a broad range of social, economic, and political factors (Dickman, 2010).

System dynamics models may facilitate our understanding of conflicts between humans and large carnivores by integrating multiple factors that influence human–wildlife conflicts (e.g., Faust et al., 2004; Nyam et al., 2020; Patana et al., 2018) and through prioritizing management actions for effective mitigation of conflicts (Mai & Smith, 2018). Forrester (1961) developed system dynamics models to simplify understanding of how a system behaves via utilizing dynamic simulation models (Beall & Zeoli, 2008; Mahamoud et al., 2013). Although the use of system dynamics simulation models in collaborative environmental problem solving is recently developed, it has been applied to several environmental problems such as air pollution, water pollution, and biodiversity conservation (Beall & Zeoli, 2008; Crookes & Blignaut, 2015; Hongli, 2013; Patana et al., 2018; Vafa-Arani et al., 2014). Yet, application of system dynamics models to wildlife management has been rare. Examples of previous models include wildlife models aimed for management of bears (Faust et al., 2004; Siemer & Otto, 2005), white-headed langur (Phan et al., 2014), and fisheries (Otto & Struben, 2004). This approach allowed these studies to identify the hidden causes of conflicts.

In this study, we developed a system dynamics model which addresses the complex interplay of social and ecological determinants shaping human–wolf negative interactions in Hamadan province, western Iran. In terms of conservation status, the gray wolf has been classified as a species of Least Concern (Boitani et al., 2018). A generalist diet and plasticity in habitat selection have enabled this species to occur across a wide range of habitats including human dominated landscapes (Mohammadi, Lunnon, et al., 2021; Shahnaseri et al., 2019). However, over the past several decades, following reductions in prey density across protected areas in Iran (Ziaie, 1996), gray wolf occurrences increased in rural areas, where they have access to anthropogenic foods, including livestock (Behdarvand et al., 2014; Mohammadi et al., 2019). Consequently, human–wolf conflicts rose dramatically (Mohammadi et al., 2019). Official records report 60 incidents of wolf attacks on people in Hamadan province from 2001 to 2018, 10 of which were fatal, with children being significantly more likely to be attacked (Mohammadi et al., 2019). With increased wolf–human conflicts in the landscape, local peoples' tendency toward retaliatory killing of wolves and wolf pups has increased (Behdarvand et al., 2014). With regard to large carnivores, livestock depredations or attacks on humans can trigger retaliatory persecution of large carnivores (e.g., Kissui, 2008).

Using system dynamics models, we investigated different scenarios to understand the effects of social and ecological factors on modulating the risk of wolf attacks on people and livestock. We sought information from local researchers and wolf experts to specify the main

issues of conflict, while exploring alternative conflicts in the future to define action-oriented policies.

2 | MATERIAL AND METHODS

2.1 | Study area

This study was carried out in Hamadan province, northwest of Iran (19,493 km^2) (Figure 1), where wolves persist in a human-dominated landscape (e.g., Ahmadi et al., 2014; Mohammadi et al., 2019). The province supports a population of over two million people, holding a mean human population density of ca. 88 inhabitants per km^2, twice the mean population density of Iran (Behdarvand et al., 2014). Main economic activities in this province are livestock production and agricultural practices, with livestock husbandry being the major source of income for the locals.

Hamadan province is regarded as one of the leading regions in agricultural production in Iran. The semi-arid landscape of this province has been highly altered as the majority of rural communities are involved in agriculture, livestock rearing, and animal husbandry (Ahmadi et al., 2014). Over the last 30 years, expansion of agricultural lands has shrunk rangelands and in turn natural habitats of wolves, reducing numbers of wild prey (Imani Harsini, 2012), such as wild goat (*Capra aegagrus*), wild sheep (*Ovis orientalis*), and wild boar (*Sus scrofa*), which are now almost exclusively found within protected areas (Ahmadi et al., 2014). There are six protected areas in Hamadan province, totaling 60,966 ha.

2.2 | Tracking of the wolves

We captured one adult male and two adult females between October 2015 and March 2017 using Belisle® traps (for more details see Mohammadi et al., 2019). The wolves were collared under permit 94/31147 issued by the Iranian Department of Environment (DoE). The GPS collars (Iridium version, FollowitTM Tellus) were programmed to acquire a position every 20 min to determine scavenging and predation events (Planella et al., 2016). The collars are programmed to automatically drop off after approximately 8 months near the end of the battery life. All GPS data will be permanently stored in the collars. Figure 1 shows the location of the three tracked wolves from three packs in Hamadan province.

2.3 | Model construction

Construction of the system model including the potential social and ecological determinants of human–wolf conflicts required a multi-disciplinary team of members with skills in agricultural activities, environmental education, social sciences, wolf behavior and conservation, system dynamics and statistical modeling (Figure 2). The team (six members) worked regularly for 2 years (2015–2017) to discuss model construction and contemplate the various social and ecological factors that shaped the growing conflicts in this province (Figure 3. Using a participatory decision-making approach, the process of model development was determined by team members.

System dynamics modeling consists of an iterative process in which each series of iterations works toward

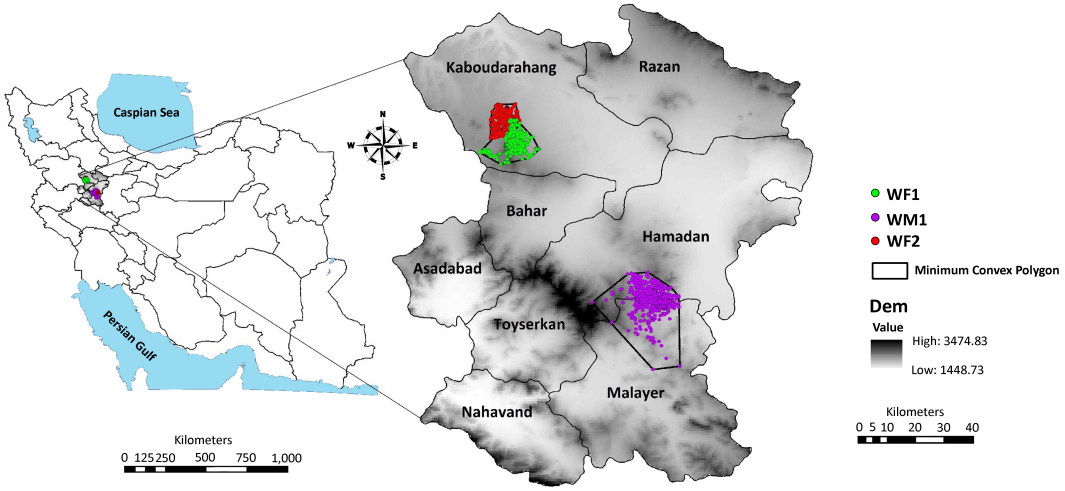

FIGURE 1 Map of Hamadan province in western Iran (left), the location of the tracked wolves illustrated using minimum convex polygons (using 100% of the locations), GPS points of the tracked wolves (WM1, WF1, and WF2), and the digital elevation model (DEM) of Hamadan province (right)

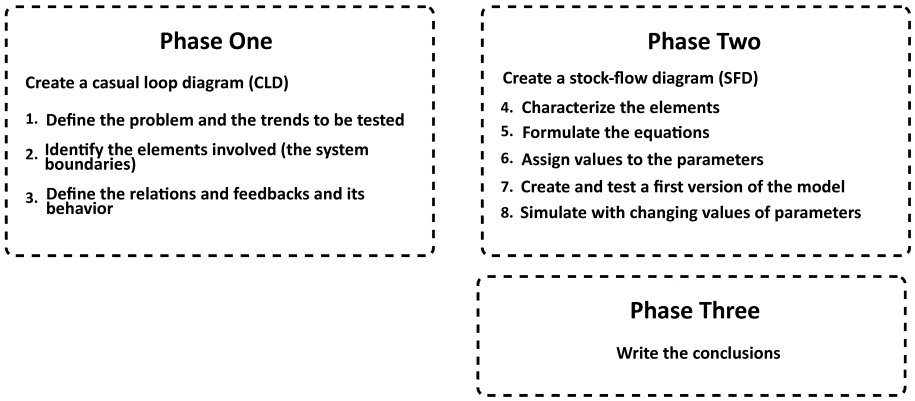

FIGURE 2 Steps of system dynamics in the present research

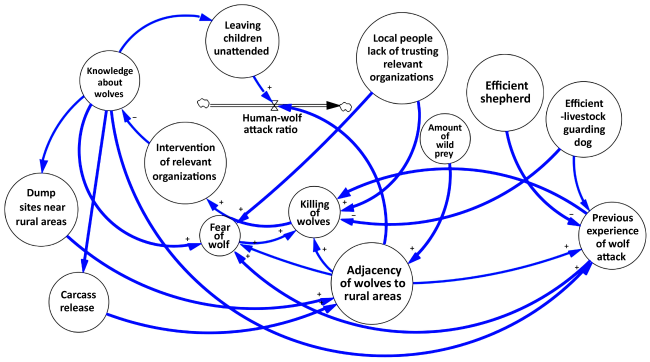

FIGURE 3 Model overview, showing causal pathways of the multiple ecological and social determinants of human–wolf incident rate. Circles indicate variables that involve ecological and social factors with time delays. Blue arrows represent cause-and-effect links

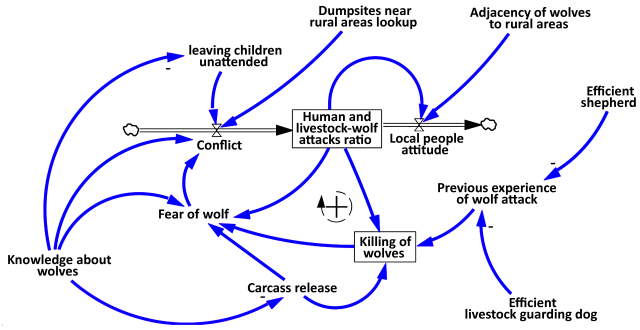

FIGURE 4 Current model overview after modifications, both structurally and with respect to data input. In this model, amount of wild prey, intervention of relevant organizations and local people's lack of trust in relevant organizations were removed from the model due to lack of information

integrating team reflection on observations, and if necessary, adjustments are also included (Mahamoud et al., 2013). The initial step of model construction was based largely on approximate data derived from surveys conducted among local people. This allowed us to investigate model configuration to be able to gradually enhance model design. The model was eventually tested in Vensim simulation software version 8.1 (Eberlein & Peterson, 1992). The model simulates over a time frame of 50 months (from 2017 to 2020). The steps of the system dynamics are shown in Figure 2.

2.4 | Model structure

2.4.1 | Causal and loop diagram

A number of models were developed over the course of 2 years (from 2015 to 2017) based on the enhancements drawn from feedback provided by wolf experts ($n = 10$), specialists in social sciences ($n = 8$), the provincial DoE of Hamadan ($n = 10$), nongovernmental organizations ($n = 5$), and data analysis of the results. The initial version of the model (Figure 2) was described as the "dynamic hypothesis," which was the starting point for model simulation based on the relationships between major social and ecological factors leading to wolf incidents. Through consultation with wolf experts and local researchers, the first version of the model underwent a series of modifications, as a result of which some variables were removed and some were added.

2.4.2 | Stock-flow dynamic model development

The second version of the model (Figure 4) represents a simplified variant of the initial model, demonstrating refinements that derived from testing the initial version and its hypothesized causal relationships against data. As inferred from the second version, a number of causal linkages from the first version that did not prove to be statistically significant were removed from the second

version of the model, as there was no information for them. For example, it was expected that the amount of wild prey would predict the adjacency of wolves to rural areas; however, there was no information to support this relationship. Hence, it was excluded from the model. Furthermore, local people's lack of trust in relevant organizations and their interventions was removed from the second model because data analysis of our findings failed to support this relationship.

2.5 | Questionnaire survey

Ethical approval was granted by the University of Tehran. Permits for local research were obtained from the DoE (permit number 94/31147) and the provincial administrative offices of Hamadan province. Each participant received a printed summary of the study, which was read to illiterate participants. Oral consent was provided by all participants prior to taking part in the survey. Social data were collected through questionnaire surveys between April and September 2015.

Based on the census data of Hamedan province, we extracted the number of households living in rural areas. The statistical sample size was then calculated based on the number of households using the Daniel method (Daniel, 1999) (Equation 1). Finally, 400 rural households randomly selected from across eight sub-districts of the province were selected as the statistical sample.

$$N = \frac{Z^2 P(1-P)}{d^2} \quad (1)$$

In this equation, Z is the Z statistic for a level of confidence, P is the expected prevalence or proportion (if expected prevalence is 20%, then $P = 0.2$), and d is the precision (if precision is 5%, then $d = 0.05$). In this research, we used $d = 0.5$ and p was selected according to family sizes in each district of rural areas.

Across the rural areas, 50 household heads were randomly selected. As men engaged in outdoor activities more frequently, we only interviewed men. In addition, men and women of these families shared similar viewpoints (based on the results of a pilot study carried out by the first author). All individuals were adults (>18 years old) and livestock owners. All interviews were conducted personally by the first author. During the interviews, we used images of carnivores living in the area including the gray wolf, red fox (*Vulpes vulpes*), golden jackal (*Canis aureus*), and striped hyaena (*Hyaena hyaena*) to assess the local people's ability to identify the wolf. Our final interviewees only consisted of those who accurately identified the wolf.

2.5.1 | Questionnaire items

The questionnaire included five categories with a mixture of open-ended and closed (yes/no; Likert scale) questions (Table 1; Table S1):

1—Personal experiences of wolf incidents (people vs. domestic animals) were measured using the following items: "*Have you or any of your family members experienced a wolf incident*?" (binary response: 1: Yes, 0: No), and "*Has any of your livestock been killed by a wolf over the last year*?" (binary response: 1: Yes, 0: No).

2—Fear of wolves was evaluated using three items: "*Are you afraid of the wolf when you see it in the wild?*" (5-point Likert scale: 1: Not at all, 2: A little afraid, 3: Do not care, 4: Somewhat afraid, and 5: Very afraid); "*Does hearing the word 'wolf' instill fear in you*"? (5-point Likert scale: 1: Not at all, 2: A little afraid, 3: Do not care, 4: Somewhat afraid, and 5: Very afraid); and "*Do you believe the presence of the wolf in the vicinity of your residential area jeopardizes your safety?*" (5-point Likert scale: 1: Strongly disagree, 2: Moderately disagree, 3: Neither agree nor disagree, 4: Moderately agree, and 5: Strongly agree).

3—Also, a question was also asked about parental care for children: "*Has any of your children ever left home unattended?*" (binary response: 1: Yes, 0: No).

4—The behavioral actions and attitudes of local people toward human–wolf conflict management in the area were measured using two items: "*How do you manage your livestock carcasses?*" and "*Which of these solutions could be effective in reducing wolf incidents?*" For the first item, the responses were: 1: Abandoning the carcass in farmlands, 2: Abandoning the carcass in rangelands, 3: Abandoning the carcass near rural areas, 4: Proper disposal of the carcass, and 5: Feeding the carcass to guard dogs. For the second one, the possible responses were: 1: Using efficient shepherds (1: Yes, 2: No), 2: Using efficient livestock-guarding dogs (1: Yes, 2: No), and 3: Removal of conflicting wolves (1: Yes, 2: No).

5—Personal knowledge about the wolf was measured using two items: "*What is the role of the wolf in the wild?*" and "*What do wolves feed on in your area?*." For the first question, the responses were: 1: To control prey population/to keep the ecological balance, 2: beauty of nature, 3: God created it so it should live, and 4: no role. For the second one, the possible responses were: 1: garbage near the village, 2: domestic animals, 3: hare and ground squirrel and Transcaucasian mole vole, and 4: All of them.

6 and 7—Furthermore, the following two variables were assessed using satellite tracking data: (1) Adjacency of the wolf to rural areas, (2) Number of wolves visiting garbage sites (Table 1).

TABLE 1 Key variables included in the model

Variables	Sources
(1) Experiences of wolf attacks on humans and/or livestock	
(1) Has any of your livestock been killed by a wolf over the past year? Yes/No	Questionnaire surveys
(2) Have you or any of your family members experienced a wolf incident (predatory attack)? Yes/No	
(2) Fear of wolves	
(1) Are you afraid of the wolf when you see it in the wild?	Questionnaire surveys
(2) Does hearing the word "wolf" instill fear in you?	
(3) Do you believe the presence of the wolf in the vicinity of your residential area jeopardizes your safety?	
(3) Leaving children unattended	
(1) Has any of your children ever left home unattended? Yes/No	Questionnaire surveys
(4) Carcass release	
How do you manage your livestock carcasses?	Questionnaire surveys
1: Abandoning the carcass in farmlands	
2: Abandoning the carcass in rangelands	
3: Abandoning the carcass near rural areas	
4: Proper disposal of the carcass	
5: Feeding the carcass to guard dogs	
Solutions for reducing wolf incidents	
(1) Using efficient shepherds	
(2) Using efficient livestock-guarding dogs	
(3) Removal of conflicting wolves	
(5) Knowledge about wolves	
What is the role of the wolf in the wild?	Questionnaire surveys
What do wolves feed on in your area?	
(6) Adjacency of wolves to rural areas	
Distance of tracked wolves to rural areas	Satellite tracking
(7) Dump sites near rural areas	
(1) Number of dumpsites near rural areas	Hamadan Department of Environment
(2) Number of wolves visiting garbage sites	Satellite tracking

3 | RESULTS

3.1 | Participants' characteristics and personal experiences with wolves and wolf incidents

The average herd size was 350 animals (total number of livestock owned by the participants: 15,000 animals: 11,850 sheep, 3150 goats). Each herd was accompanied by one shepherd and an average of 1.3 herding dogs (28.8% of the herds had no dogs, 31.5% had one, 23.8% had two, and 15.9% had three or more dogs). Only 13.5% of the participating herders had full insurance for their livestock.

Among the participants, 60% reported experiences of wolf incidents on livestock in 2015 (63.2% reported livestock losses due to wolf incidents over the past decade), with a total of 590 sheep and goat deaths reported to be killed by wolves during that year. On average, each herder reported losing 1.4 head of livestock during 2015 (1.4 ± 2.2). More than half of the incidents were reported in herds with one guarding dog and one shepherd (58%). During the study period (between April and September 2015), participants reported the loss of at least 3851 sheep and goats due to non-predatory causes (mostly diseases; on average, each herder reported losing 9.6 ± 13.5 livestock). According to our questionnaire surveys, lack of access to efficient husbandry systems and veterinary care

is the main reason for non-predatory deaths. Among the participants, 40% reported experiences of wolf incidents on people (10% resulted in death of a family member, mostly children ($n = 24$) and the elderly ($n = 16$), while 30% ($n = 120$) resulted in human injuries). incidents often occurred when children were left unattended near farmlands (30%), or when the elderly worked alone on farmlands (10%) (Behdarvand & Kaboli, 2015). Additionally, 55% of the respondents' children had left home unattended at least once.

3.2 | Fear of the wolf

The majority of the respondents were afraid of wolves (66.1%) and feared the sight of a wolf in the wild (66.5%). Most respondents (74.1%) believed that the presence of a wolf in the vicinity of their residential area jeopardized their safety.

3.3 | Behavior (management solutions and management actions)

The majority of the respondents selected the following options as the most effective in reducing wolf incidents: (i) increasing wild prey populations (98.8%), (ii) providing educational programs for local communities (98.2%), and (iii) implementing a proper waste management plan (96.2%). However, locals often disposed of their livestock carcasses near farms, in rangelands, or close to settlements (63.5%). Only 36.5% of the respondents properly managed livestock carcasses (food for herding dogs [14.5%] or proper disposal [22%]) and therefore had fewer experiences of incidents (only 9%).

3.4 | Simulation scenarios

To investigate the effects of social and ecological factors or their combination in shaping wolf incidents rates, we tested four sets of plausible simulation scenarios as discussed below:

(i) Current scenario: wolves approach villages at a maximum of 2.5 km, there are 100 shepherds and 100 efficient livestock guarding dogs per 10 km^2, and local people's knowledge is also at the lowest possible level.

(ii) First scenario: wolf distance from villages has increased (to 5 km) and knowledge of local people toward wolves has doubled.

(iii) Second scenario: wolf distance from villages has increased (to 10 km) and knowledge of local people is assumed to remain at a similar level to that of the first scenario.

(iv) Third scenario: knowledge of local people has doubled. Also, the number of shepherds and efficient livestock guarding dogs has doubled (200 per 10 km^2).

3.5 | Model outputs

3.5.1 | Current scenario

In the current scenario, the simulation results suggest an increase in killing of wolves (see Figure S1a). Furthermore, the rate of wolf incidents (Figure S1b) and leaving children unattended will both show constant trends (100 children) (Figure S2c). During the first month, there will be an increase in the conflict rate, which will later follow a steady trend (Figure S2d). Local people will adopt a more negative attitude toward wolves (Figure S3e). Local communities' fear of wolves will experience an increase during the first month, but will reduce from the fifth month onwards (Figure S3f). Improper open dumping of domestic animal carcasses will have an increasing trend during the 10th month, but exhibit a steady trend thereafter (Figure S3g).

3.5.2 | First scenario

In the first scenario, results of simulation suggest that, despite the rise in awareness of local communities toward wolves, killing of wolves by local communities will continue to increase. However, local communities' attitude toward wolves will improve as compared to the current scenario (Figure S4a,b).

3.5.3 | Second scenario

In the second scenario, the simulation results indicate that killing of wolves by local communities and wolf incidents on humans and livestock will considerably reduce as compared to the first scenario (Figure S5a,b). Conflicts between local communities and wolves will increase during the first months, but will reduce to zero after 2 months (Figure S5c).

3.5.4 | Third scenario

In the third scenario, the results show that killing of wolves by local communities, wolf incidents on humans and livestock, leaving children unattended, and human–wolf conflict will reduce sharply (Figures 5 and 6).

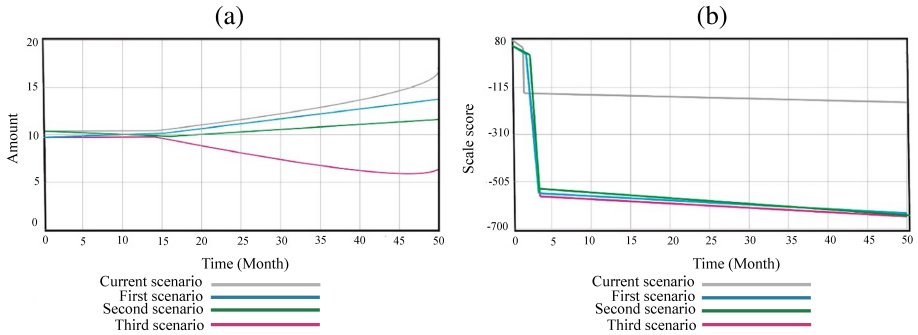

FIGURE 5 Simulated dynamics of killing of wolves (a) and rate of human and livestock wolf incidents (b) in the third scenario among local communities of Hamadan province

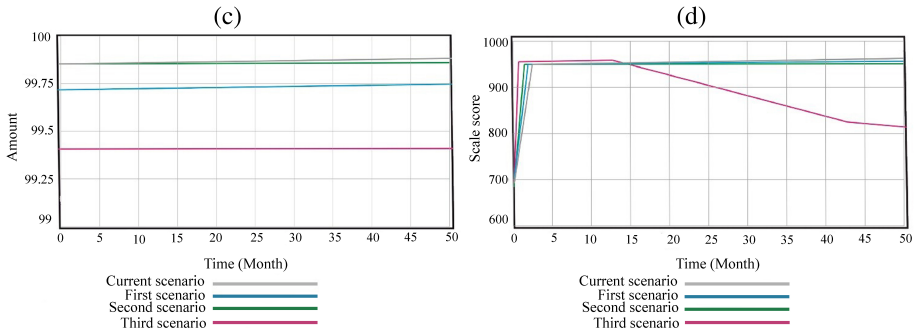

FIGURE 6 Simulated dynamics of leaving children unattended (a) and conflict (b) in the third scenario among local communities of Hamadan province

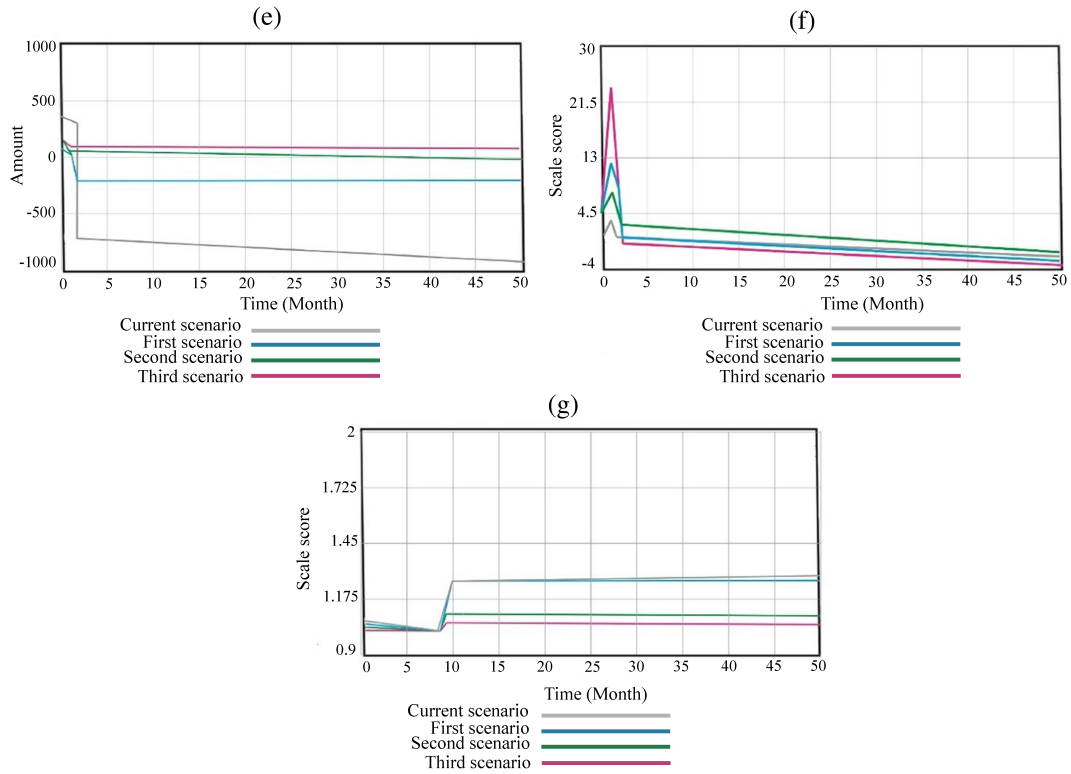

FIGURE 7 Simulated dynamics of local people's attitude (a), local communities' fear of wolves (b), and dumping of domestic animal carcasses (c) in the third scenario among local communities of Hamadan province

Furthermore, local people's attitude toward wolves will improve as local communities' fear of wolves will decrease (Figure 7). Dumping of domestic animal carcasses by local communities will decrease compared to the previous scenarios and will follow a steady trend from the tenth up to the fifth month (Figure 7).

4 | DISCUSSION

The increasing overlap between large carnivores and humans in some areas calls for improvement in educational programs and prevention guidelines to reduce human-large carnivore conflicts (Espinosa & Jacobson, 2012; Johansson et al., 2017; López-Bao et al., 2017). Here, we demonstrate how system dynamics models could be utilized to address the complex social and ecological causal pathways influencing wolf incidents on humans and livestock. With the help of system dynamics processing, one is able to investigate the structure, interactions and mode of behavior in complex systems and sub-systems, and to study, evaluate, and predict the changes in the system in an integrated, holistic manner. The method allows for a more detailed and quantitative approach to simulation and produces more reliable results (Kollikkathara et al., 2010; Pizzitutti et al., 2017).

4.1 | Main lessons from Iran

According to the results of the interviews with local communities as well as information obtained from satellite tracking of wolves, various factors affecting wolf incidents on humans and livestock in NW Iran were identified:

4.1.1 | Livestock carcass management

Over the past 100 years, the majority of nonlethal wolf incidents in North America have involved wolves habituated to human food and garbage (e.g., Linnell et al., 2002, 2021). Prevention of wolf habituation in this area has been known as a key to reducing human–wolf conflicts (Linnell et al., 2002, 2021). In NW Iran, the majority of local communities (63.5%) abandoned their livestock carcasses in backyards, close to agricultural lands, rangelands, and rural areas (Figure S7). Analysis of feeding clusters of the tracked wolves confirmed that scavenging of livestock carcasses was higher than hunting and feeding on natural prey, similar to the findings of Hosseini-Zavarei et al. (2013) in central Iran. Feeding clusters showed that scavenging was highest in summer owing to livestock mortality due to brucellosis (Mohammadi et al., 2019). Based on the present and previous studies (Mengüllüoğlu et al., 2019; Musiani & Paquet, 2004), it appears that reinforcement of wild ungulates may be the ultimate solution. However, Hamadan province is a center of agricultural production in Iran where the area of agricultural lands has increased from 46,820 to 550,264 ha over the past 30 years (Ahmadi et al., 2014). At the same time, the remaining suitable habitats are no longer sufficient to support the reintroduction of wild ungulates. As a result, a viable solution to minimizing human–wolf encounters in this area is educating local people on proper methods of disposal through burial.

Given that the size of the core area for the tracked wolves in Hamadan province is 36 km^2 (Mohammadi, 2017), a buffer of the same size was created around protected areas and the number of incidents by wolves on humans was counted within the buffer. The results showed that as protected areas cover 3% of the area of Hamadan province, only two of the 60 incidents had occurred within protected areas. This indicates that access to livestock carcasses and poorly-constructed dumping sites attracts wolves to rural areas, increasing human–wolf encounters (Mohammadi et al., 2019; Mohammadi, Lunnon, et al., 2021). Our results are in line with Treves et al., 2011, suggesting that conflict rates will boost by proximity to wolf territories.

4.1.2 | Waste management

People in most rural areas in Iran still rely on open dumping, which is one of the most primitive methods of waste disposal (Figure S7). Open dumping sites and poorly constructed landfills are accessible to wildlife and impact their ecology and behavior (Newsome & Van Eeden, 2017), bringing together different species of carnivores (Peirce & Van Daele, 2006). A study in Nevada, USA, has shown that landfills increase black bear (*Ursus americanus*)-vehicle collisions (Newsome & Van Eeden, 2017). Landfills can also increase populations of opportunistic species such as wolves, which in turn increases wolf-livestock and wolf-humans encounters (Newsome & Van Eeden, 2017). It has also been reported that the presence of both feral dogs and wolves at landfills in Italy has increased wolf-dog interbreeding (Newsome & Van Eeden, 2017). Moreover, the presence of animals (particularly feral dogs) and livestock in poorly constructed landfills contributes to the spread of diseases such as rabies and distemper to livestock or even humans (Nayeri et al., 2021; Newsome & Van Eeden, 2017). Another consequence of wildlife feeding on landfills is the presence of non-degradable plastic in their bodies. For the maned wolf (*Chrysocyon brachyurus*), it has been shown that non-digestible anthropogenic waste such as plastic comprised 14.1% of its diet (Silva & Talamoni, 2003) and was present in up to 40% of scats (Aragona & Setz, 2001).

In our study area, villages are bereft of efficiently structured waste disposal sites and local communities use open unsanitary dumpsites close to rural areas (Mohammadi et al., 2017; Mohammadi et al., 2019; Figure S7). This further attracts facultative scavengers and increases the probability of potential risky encounters (Distefano, 2005; Newsome et al., 2016). When livestock are kept within pen

enclosures in villages during the fall and winter, these dumpsites are important feeding locations for carnivores. Management of *unsanitary* waste dumps and dumping of livestock carcasses minimizes chances of human–wolf and livestock-wolf incidents (Peirce & Van Daele, 2006; Tourani et al., 2014). We recommend that fences with a minimum height of 180 cm be built around dumping sites, with a portion of the fence (40–50 cm) being installed underground to prevent access to the site by burrowing carnivores.

Regularly burying or burning carcasses in a pit is a useful way to deter wolves from frequenting rural areas. Securing the dump sites with electric fencing offers additional protection from wolves. Constructing a rendering facility, a commercial landfill, or a carcass-composting site is believed to be the best way to ensure carcasses are properly disposed; however, if none of these alternatives are available, the practice of burying carcasses or using a carcass pit could be the next best option (Stone et al., 2008).

4.1.3 | Leaving children unattended

Nearly half of the well-documented reports of incidents on humans by large carnivores in North America entail risk-enhancing behaviors by humans, mostly leaving children unattended (Penteriani et al., 2016). According to a study conducted by Naha et al. (2018), a greater number of leopard incident victims in India were children and young people. Their results showed that victims were often working alone on agricultural lands, walking home after school, returning from the market, or collecting firewood. In another research, Bombieri et al. (2019) indicated that 63% of brown bear incidents occurred when the victim was alone at the time of the incident and 50% of the incidents occurred when people were engaged in leisure activities.

3In Hamadan province, most wolf incidents occurred when small children were left unattended close to farmlands and/or when the elderly worked alone on farmlands (see also Behdarvand & Kaboli, 2015). Therefore, not only is it important that guidelines are made available, but also proper enforcement of such guidelines is essential. All interviewees expressed their deep feelings and hate toward the wolves that attacked children. Killing of wolves that approach villages is therefore considered as the most effective solution among local communities to reduce wolf incidents.

4.1.4 | Lack of livestock guarding dogs and shepherds

Lack of livestock guarding dogs and shepherds is also a key factor that increases livestock depredation. Most respondents had few guarding dogs, hardly enough compared to the large herd size. Information on the effectiveness of conflict mitigation interventions, such as the use of livestock guarding dogs, is limited in Iran, making it difficult to delineate proper guidelines in each particular context (Farhadinia et al., 2017; Khorozyan et al., 2017). Therefore, we recommend the implementation of pilot programs to scientifically test the effectiveness of livestock guarding dogs through standard designs (Eklund et al., 2017; Treves et al., 2019). Electric fences, guarding animals, physical deterrents, and calving control have been recently regarded as the most effective solutions for reducing livestock depredation (Bruns et al., 2020; Khorozyan et al., 2020; Khorozyan & Waltert, 2019a, 2019b). According to a study by van Eeden et al. (2018), livestock guarding dogs were highly effective in reducing livestock losses. Their results showed that lethal control was the second most effective control although its success varied significantly. In another research by Krafte Holland et al. (2018), the most commonly recommended interventions for reducing livestock depredation involved improved livestock husbandry techniques (e.g., fencing and guard dogs).

Deterrent devices are often used in mechanized and intensive animal farming systems to keep predators away. In Iran, however, animal farming is still practiced using traditional methods (grazing in open rangelands at dawn accompanied by a shepherd and a few dogs and returning to the village at dusk); therefore, only the use of well-trained local shepherd dogs could be effective in reducing livestock depredation.

4.1.5 | Increasing awareness on how to coexist with wolves

Lack of knowledge about carnivores is known to be a significant factor in influencing local communities' attitudes toward wolves in Muslim countries (Bhatia et al., 2017). Studies suggest that local people with an extensive knowledge of wolf behavior reported more positive feelings, while those with knowledge based on personal experiences of wolf depredation had negative feelings (Glikman et al., 2012; Johansson et al., 2017).

Efforts to reduce human fear of wolves should consider minimizing risky encounters for people (Mohammadi, Alambeigi, et al., 2021). Decrease in fear will lead to reduction in persecution of wolves. Thus, an important strategy for reducing wolf incidents in this area is to implement a communication program to raise awareness on how to facilitate human–wolf coexistence. Preventing potential conflict situations heavily depend on how people behave in wolf areas. Therefore, human–wolf coexistence would

benefit from encouraging changes in human behavior. Awareness campaigns should adopt strategies to influence human behaviors (Balmford et al., 2021; Cinner, 2018; Nielsen et al., 2021) with the potential to impact on reducing risky situations with wolves. Here, we have highlighted several behavioral changes that should be prioritized: not leaving children unattended, adopting preventive damage measures and waste management practices. For instance, in the same way that social marketing has been used to increase recycling (e.g., Andreasen, 2006; Haldeman & Turner, 2009), community-based social marketing campaigns in public meetings using the media, or in schools, could be used to improve waste management, reducing access opportunities of wolves to garbage. Social marketing is increasingly considered an important tool to promote human–wildlife coexistence (Carter & Linnell, 2016). For instance, Saypanya et al. (2013) found that after establishing social marketing campaigns, local communities' attitude and knowledge toward tigers (*Panthera tigris*) improved.

5 | CONCLUSION

Attracting wolves to rural areas is the key factor affecting the rate of wolf incidents on humans and livestock. By changing different variables that attract wolves in multiple scenarios (appropriate management of dump sites), when the distance between wolves and human settlements increases, the rate of wolf incidents on humans and livestock as well as killing of wolves by local communities decreases. We recommend the use of efficient guard dogs to reduce wolf incidents on livestock. It is also strongly recommended to enhance parental care in order to protect children from possible incidents, especially during spring and summer. We urge the provincial office of environment of Hamdan and nongovernmental organizations to boost awareness and act to improve attitudes toward wolves through educational programs on how to coexist with wolves and allow local people to redevelop personal experiences with wolves (Mohammadi, Lunnon, et al., 2021).

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest.

AUTHOR CONTRIBUTIONS

Alireza Mohammadi, Amir Alambeigi, and Mohammad Kaboli: Conceptualization, Methodology, Software. Alireza Mohammadi, Mohammadi Kaboli, José Vicente López-Bao, and Lobat Taghavi: Data curation, Writing-Original draft preparation. Alireza Mohammadi: Visualization, Investigation. Mohammad Kaboli, José Vicente López-Bao, and Amir Alambeigi: Supervision. Alireza Mohammadi and Amir Alambeigi: Software, Validation. Lobat Taghavi, José Vicente López-Bao, and Mohammad Kaboli: Writing-Reviewing and Editing.

ETHICS STATEMENT

All aspects of this study were approved by University of Tehran and the DoE (permit number 94/31147).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available upon request from the corresponding author.

ORCID

Alireza Mohammadi https://orcid.org/0000-0003-3701-6455

Mohammad Kaboli https://orcid.org/0000-0002-9203-2346

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