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ORIGINAL RESEARCH

Assessing spatio-temporal patterns of human-wildlife conflicts in a human-dominated landscape: a case study from Iran

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Abstract

Human-wildlife conflict is considered one of the significant challenges that conservation authorities face in managing protected areas and the surrounding lands. This study aims to investigate the spatial and temporal trends and characteristics of conflicts between rural communities and wild animals in a protected area in northeastern Iran. We collected data on wild animals' attacks on humans and livestock and damages to crops within the Ors-e-Sistan Protected Area (OSPA) and its 5 km buffer zone for 2010–2020 via official reports and questionnaire surveys (n = 373). We found that multiple species-specific and human-related factors determine conflict hotspots in space and time. Wild boars (*Sus scrofa*), wolves *(Canis lupus)* and leopards *(Panthera pardus saxicolor)* were perceived to be responsible for the highest number of attacks on humans and livestock. Wild boars were responsible for more than 90% of attacks on agricultural lands. Hotspots of attacks on livestock were located in the pastures around villages and pastures within the protected area. In contrast, hotspot areas of attacks on humans and damage to crops were located in the orchards and farms of villages on the protected area's northern and southern fringes. Temporal patterns in the variability of conflict revealed that grazing seasons and species' nocturnal behaviors caused more attacks and damages during warm seasons and nights. Conflict hotspots and their temporal clustering, identified in this study, can guide managers to focus mitigation activities in prioritized areas and allocate management resources that reduce conflicts between people and wild animals. The assessment of the type of species and their characteristics, land-use type, and distribution of human settlements is recommended when identifying locations and occasions of conflicts.

Keywords Conflict hotspot mapping · Conservation conflict · Human–wildlife conflict · Protected area management · Livestock predation · Mitigation

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Introduction

Human-wildlife conflict is a significant challenge faced by conservation authorities and researchers worldwide (Cretois et al. 2019; Torres et al. 2018), particularly in areas neighboring protected areas (Tiller et al. 2021). Human-wildlife conflict refers to the interaction between wild animals and people, which may negatively impact both groups: people and their resources or wild animals and their habitat (Ruda et al. 2018). Generally, human-wildlife conflicts generally consist of four types: attacks on humans (resulting in deaths, injuries, and threats), crop damage, property damage, and livestock predation. Large and medium-sized carnivores, such as wolves (*Canis lupus)* and leopards (*Panthera pardus*), are forced to share space and resources with people beyond protected area boundaries to meet their biological needs (Naha et al. 2021; Soofi 2017), leading to human-carnivore conflicts (Inskip and Zimmermann 2009). Wild animals may attack humans and livestock or damage crops, which sometimes leads to humans' retaliatory killing of the animals. Previous studies have shown that conflicts increasingly threaten the survival of wild carnivores along the borders of protected areas where they interact with humans. Therefore, these conflicts should be the research focus to plan management strategies that balance wildlife conservation, human safety, and livelihoods (Meena et al. 2014). Large or medium-sized herbivores can cause conflicts when they feed on and damage crops and forage. For instance, habitat loss and fragmentation have increased African elephant (*Loxodonta Africana*) conflicts (Noga et al. 2018). Wild ungulates usually compete with domestic livestock for forage. However, due to the more severe damage caused by carnivores to livestock and humans, and people's fear of large carnivores, carnivore-induced conflicts have been more extensively studied than those related to herbivores (Xu et al. 2020).

One of the primary reasons for human-wildlife conflicts is the rapid growth of human populations and the conversion of wildlife habitats into pastures, agricultural lands and human settlements (Makindi et al. 2014). The fear experienced by wild animals due to human presence may force them to adjust their activity to avoid confrontation. Since this avoidance is not always possible in human-dominated landscapes, the co-occurrence of wild animals with humans is inevitable. Therefore, animals try to change their foraging time which can affect animal physiology and demography and trigger trophic cascades (Gaynor et al. 2018).

One of the factors causing conflicts between humans and wild animals is limited resources that need to be shared by both parties. This often results in competition between humans and wild animals to access these resources (Graham et al. 2005). In some cases, damages caused by species such as wild boars can be attributed to increased populations due to habitat destruction, and decreased carnivores such as wolves and leopards, their natural predators (Rao et al. 2015).

Aside from financial losses due to conflicts such as crop damage, livestock loss, and human injury or death, wild animal attacks can also lead to negative attitudes among local people towards wildlife (Carter et al. 2015). Without adequate measures to reduce these conflicts, the tolerance of local people towards wildlife may decrease, which can lead to retaliatory actions such as illegal hunting, trapping, the use of poisonous prey, and threatening the safety of these animals (Behmanesh et al. 2017). This is particularly true for species from the Felidae family, such as leopards that attack livestock and cause financial loss, leading to rural people's negative perceptions towards them (Inskip and Zimmermann 2009).

For example, it has been reported that one of the main challenges of the Persian leopard conservation program in northeastern Iran is the retaliatory killing of the animals by ranchers who have lost their livestock due to these attacks (Soofi 2017).

Many efforts have been made to understand the various aspects of human-wildlife conflict (Kuiper et al. 2021; Treves and Santiago-A´ vila 2020; Zimmermann et al. 2021). For instance, in Iran, Soofi (2017) investigated human conflicts with leopards and wolves in a national park. The study employed interview surveys to identify the key underlying factors contributing to attacks. The results revealed that presence and number of guard dogs were the most significant predictors of livestock mortality caused by leopards and wolves, respectively. In another study conducted in Kenya, Tiller et al. (2021) examined seasonal and spatial trends of elephant *(Loxodonta africana)* conflicts with humans in specific national reserve areas over 15 years. The findings demonstrated changes in crop-raiding patterns in terms of time and location. The increase in human population and agricultural activities increased in crop-raiding incidents between 1999 and 2000. Moreover, the crop-raiding incidents were highly concentrated based on the types of elephant groups (Kshettry et al. 2017). Recent studies have focused on analyzing these conflicts spatial and temporal characteristics. Collecting spatio-temporal data on wildlife attacks enables conservation authorities to prioritize areas that require targeted efforts to reduce human-wildlife conflicts (Kshettry et al. 2017). For example, Ruda et al. (2018) investigated potential interactions between the spatial locations of wild animal attacks on humans in a national park and its surroundings in Nepal over ten years. Another study, the spatio-temporal patterns of lion predation on livestock in an Indian national park were examined using existing records and human perceptions collected through interview surveys (Meena et al. 2014). Mukeka et al. (2020) assessed human-wildlife conflict reports for multiple wildlife species in Kenya's largest protected area over 23 years. Their findings revealed temporal variations in reported conflict incidents by year and season, influenced by rainfall fluctuations affecting food and water availability, quality, and distribution. Furthermore, spatial differences in conflict incidents were observed across different parts of the protected area, correlating withhuman population growth rates and densities.

Identifying priority areas for human-wildlife conflict, where conflict mitigation measures can be practical, poses a significant challenge in wildlife management. To address these conflicts, it is crucial to develop appropriate measures. Understanding the spatial interactions between humans and wildlife offers valuable information on conflict hotspots (Miller 2015). However, a lack of information about conflict sites can result in the improper allocation of protection facilities and funding resources to compensate victims, increasing tensions between people and wildlife and intensifying retaliatory measures (Karanth et al. 2012). Lack of time, administrative bureaucracy, and non-payment of compensations are reasons that can hinder the collection of spatio-temporal data on wildlife conflict cases by conservation authorities, limiting access to valuable information. This information serves as a solid foundation for assessing human-wildlife conflicts.

The OSPA in Iran, classified as category VI according to the IUCN protected area classification, harbors a wide range of wildlife species. The numerous villages, orchards, farmlands, and extensive pastures in and around this area potentially pose a risk of conflict between rural people and wild animals, resulting in attacks on humans and livestock as well as crop damage. Effective management of these conflicts relies on the quantitative and qualitative evaluation of their characteristics. To our knowledge, no study has been conducted

in Iran to assess conflicts between rural people and all wild animal species in a single case study. This study aims to assess the spatial distributions, temporal and seasonal patterns, and characteristics of conflicts between wildlife and people residing in villages in and around OSPA during over ten years (2010–2020). In addition to utilizing existing conflict records, we applied a public participation approach to collecting information from rural communities regarding conflict cases, enabling us to assess the losses and damages caused by wild animal attacks on humans and livestock and crop damages. We discuss the findings and provide recommendations for management interventions to reduce and mitigate human-wildlife conflict in the OSPA and its surrounding areas, which humans predominantly inhabit.

Materials and methods

Study area

The OSPA is located in the north of Khorasan-Razavi province in Iran, covering an area of 112,714 hectares (Fig. 1). The Hezar-Masjed Mountain range surrounds it. This protected area encompasses approximately 50% of pastures, 45% of forests, 3% of agricultural lands, and 2% of barren land. As one of northeast Iran's most significant Juniper (*Juniperus excelsa*) forest habitats, OSPA contains harbors over 190 plant species from 53 families, including Terebinth (*Pistacia terebinthus)*, Redcurrant (*Ribes rubrum*) and Caraway (*Carum carvi*), which are highly valued for conservation. This protected area hosts an assemblage of mammals, such as Persian leopard (*Panthera pardus saxicolor*), Urial wild sheep (*Ovis*

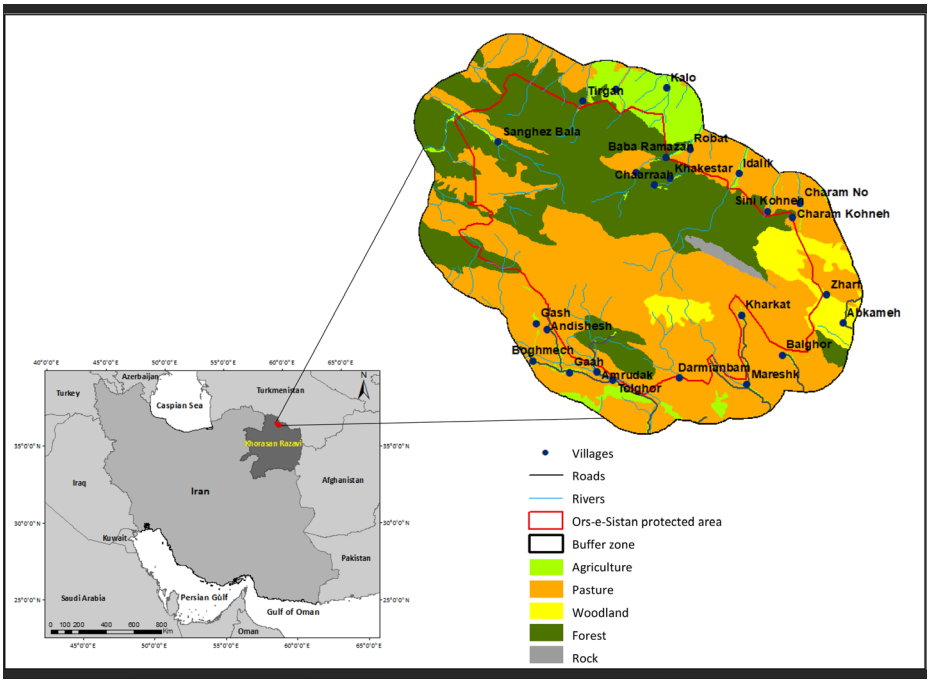

Fig. 1 The map of study area, Ors-e-Sistan protected area and its buffer zone

orientalis arkali), Wild goat (*Capra aegagrus*), gray wolf (*Canis lupus*), Wild boar (*Sus scrofa*), red fox (*Vulpes vulpes*), Indian crested porcupine (*Hystrix indica*), striped hyena (*Hyaena hyaena*), golden jackal (*Canis aureus*), jungle cat (*Felis chaus*) and Pallas's cat (*Otocolobus manul*) (Karami et al. 2016).

Within the boundaries of OSPA were seven villages, four inhabited, with a total population of 115 individuals. The remaining villages were uninhabited. Additionally, 30 villages were located within the 5 km buffer zone of the protected area. Of these, 21 villages had over than 50 households, with a total population of 12,841 (Statistics Center of Iran 2016). Most residents in the inner villages and some in the surrounding villages were traditional ranchers who relied on the pastures inside and around OSPA. Apart from the village residents, various nomadic tribes migrated from villages outside the 5 km buffer zone to utilize the pasture lands inside OSPA from late spring to mid-summer for livestock grazing (Bagheriyan 2019). Villages such as Tolghor, Amrudak, Gaah, Boghmech, Mareshk and thier neighboring areas, with permanent rivers, experienced more successful gardening. Rice, barley, and wheat cultivation were common in certain villages, like Robat, Baba Ramazan, and Idalik.

Sampling and data collection

This study encompassed all conflict cases involving attacks on humans and livestock, and crop damages inside OSPA and the 5 km buffer zone between 2010 and 2020. Initially, we conducted field visits, and consulted with conservation officers of the Department of Environmental Protection (DEP) and local informants well-acquainted with the study area, including community representatives. Two methods were employed to collect data related to human-wildlife conflict cases in the villages within and around OSPA. Firstly, we examined the previous reports of wild animal attacks on humans, livestock, and crop damage in the study area over the past ten years available in the DEPs of the cities where OSPA was located. We extracted information on the history and location of attacks, the types of wild animals involved and the type and extent of damages or losses, including compensations awarded. Secondary datasets on human-wildlife conflict incidents have previously been utilized in previous studies (Mukeka et al. 2020; Sharma et al. 2020; Tripathy et al. 2021). These data were recorded based on reports from residents to the DEPs and were subsequently evaluated and validated by conservation officers within the departments.

We employed the public participation approach to collecting data on instances of human-wildlife conflict in the study area through questionnaire surveys conducted via face-to-face interviews. The initial section of the questionnaire consisted of inquiries regarding the socio-economic characteristics of the participants, including age, occupation, and education. The following questions focused on the date, time, and location of wild animal attacks on humans, livestock, or crop damage over the past decade. The questions also sought to identify the species of wild animals involved and the type and extent of the damages or casualties resulting from these incidents.

For this study, we considered all villages located within the OSPA and the 5 km buffer zone, which encompassed 37 villages and a total population of 12,956 individuals as the statistical population. Among these villages, those inhabited within the designated area (4 villages) and villages with over 50 households located within the buffer zone (21 villages), where human-wildlife conflicts had occurred, were identified as target villages, and their 12,279 inhabitants were selected for sampling. Villages with a history of human-wildlife

conflict were identified based on data collected from the DEPs and consultations with rangers and residents.

Throughout multiple visits to the target villages during the summer and autumn of 2021, we randomly distributed 373 questionnaires within the study area. The number of questionnaires allocated to each village was determined proportionally according to its population about the total population of the target villages. To ensure data quality, 41 questionnaires were completed in villages outside the 5 km buffer zone to document conflicts between wildlife and nomadic communities that migrated to summer pastures within the region. In some instances, village council members and educated locals were enlisted to distribute the questionnaires and to record geographic coordinates of the attacks using handheld Global Positioning System (GPS) receivers. We recorded the locations of wild animal attacks on livestock in the pastures within the OSPA, as well as conflict incidents involving nomads migrating from villages outside the buffer zone to pastures within this area, to enhance the quality of the data for mapping conflict hotspots.

Data analysis

All collected data from the available reports and completed questionnaires were aggregated and transferred to Excel files. Spatial and temporal distributions and the characteristics of wildlife attacks and damages were assessed using descriptive analyses in Microsoft Excel v. 2013 (Microsoft Corporation 2018), a0 (IBM Corporation 2021) and spatial analyses in ArcGIS v. 10.6. (ESRI 2018). We utilized kernel density as one of the techniques to identify conflict hotspots based on point data, generating a surface that indicates the intensity of these events. The intensity of conflict incidents was estimated using the following equation:

$$\lambda_{\tau}(S) = \sum_{i}^{n} \frac{1}{\tau^2} K\left(\frac{(S - S_i)}{\tau}\right)$$

Where τ is the bandwidth or the size of the kernel (3 km), K is the kernel function that indicates the shape of the kernel, and S is the intensity of the event (Bailey and Gatrell 1995). Furthermore, we utilized chi-square tests to investigate variations in the relative frequencies of conflicts caused by different species, with significance tests conducted at $p = 0.05$.

Results

Respondent profile

The majority of respondents (60.16%) were aged between 40 and 60 years old. 17.58% were between 30 and 40 years old, and the age group of 60 to 70 accounted for 16.21% of the total respondents. Among those recruited for the social survey, 22% were illiterate, 73% had formal education ranging from primary to high school, and 5% were graduates. Farming (annual crops), ranching, and gardening (fruit trees) were the primary occupations of the respondents. 29% of the respondents were farmers and ranchers, 23% were only ranchers, 18% practiced ranching and gardening, 16% were gardeners, and 5% were farmers. Approximately 75% of the respondents reported wild animal attacks on their livestock and

poultry, 73% believed that these species caused damage to their orchards and farmlands, and 8% experienced wild animal attacks at least once in their lifetime.

Conflict characteristics based on different species

A total of 1,419 conflict cases containing attacks on humans and livestock and crop damage were collected through social surveys and existing reports in OSPA and the buffer zone for 2010–2020 (Table 1). The record of the coordinates of 122 locations of wild animal attacks on livestock in pastures around villages, and 7 cases in pastures inside the protected area in the target villages, was impossible due to limited access to the locations. Therefore, they were only included in the total number of attacks and excluded from the hotspot analysis. Wolves were responsible for the highest number of attacks on humans and livestock (41.44%) during the studied period, followed by wild boars' attacks on humans and crop damage (40.66%), and leopards' attacks on humans and livestock (9.09%), respectively. The highest (n = 200) and lowest (n = 54) conflicts, attacks, and damages occurred in 2016 and 2010.

Out of the 1,419 number of the reported conflict cases, 31 cases of attacks occurred on humans, 768 cases of attacks happened to livestock and poultry, and 620 cases of damages were related to orchards and agricultural lands in the study area. The geographical coordinates of 1,290 locations of conflicts were recorded, consisting of wild animals' attacks on humans (31 cases) and on livestock and poultry (639 cases), as well as crop damage (620 cases) (Fig. 2). These locations were used for mapping conflict hotspots in the study area.

Wildlife attacks on human

The distribution of attacks on humans by different wildlife species shows that wild boars were responsible for the highest number of attacks (58%), followed by snakes (19.35%), wolves (16.13%), and Persian leopards (6.45%) (Online Resource 1: Fig. 1) ($\chi^2 = 5$, df = 5,

Table 1 Annual number of conflicts (attacks and damages) which occurred inside OSPA and surrounding buffer zone, during 2010–2020

Year	Leopard	Wolf	Jackal	Hyena	Fox	Snake*	Wild boar	Porcupine	Total
2010	0	17	1	2	0	1	33	0	54
2011	7	36	0	1	0	0	37	0	81
2012	12	39	1	1	0	1	36	0	90
2013	4	35	1	1	0	2	47	2	92
2014	5	65	3	0	0	0	52	5	130
2015	8	68	0	0	0	0	39	1	116
2016	18	83	6	1	0	2	80	10	200
2017	18	64	4	0	1	1	76	9	173
2018	29	64	14	0	1	2	73	14	197
2019	18	71	5	3	4	0	62	12	175
2020	10	46	4	0	2	2	42	5	111
Total	129 (9.09%)	588 (41.44%)	39 (2.75%)	9 (0.63%)	8 (0.56%)	11 (0.78%)	577 (40.66%)	58 (4.09%)	1419

• *Snake bites were caused by two species: west-Asian blunt-nosed viper (Vipera lebetina obtusa) and central Asian Cobra (Naja naja oxiana)*

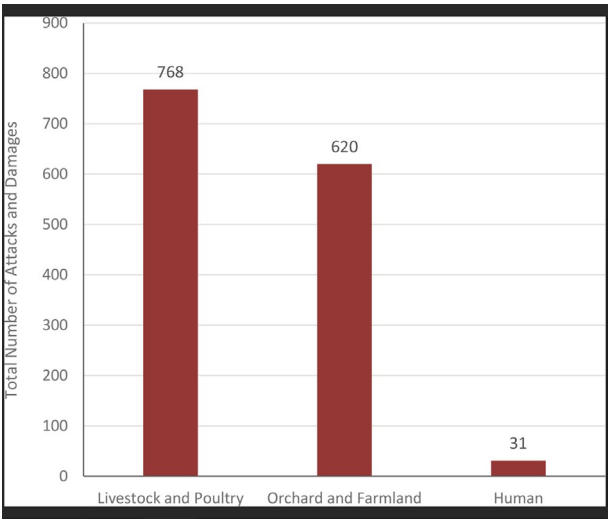

Fig. 2 Total number of attacks on humans, livestock and poultry, and damages to orchards and farmlands by wild animals in the study area during spring 2010 to autumn 2020

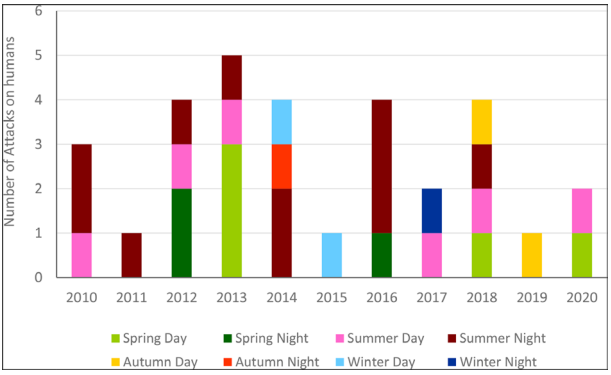

Fig. 3 Year, season and time of wild animals' attacks on human in the study area during spring 2010 to autumn 2020

p-value > 0.05). None of the attacks on humans were fatal. The highest number of attacks occurred in spring 2013 during daytime, and in summer 2016 during nighttime (Fig. 3). Based on the results, 62.22% of the attacks occurred during nighttime, and 37.78% of the attacks occurred in the daytime (χ^2=4.839, df=3, p-value > 0.05). There were significant seasonal differences in the wildlife attacks on humans (χ^2=25.175, df=9, p-value=0.003). Most attacks occurred in summer (42.22%), followed by autumn (33.33%) and then spring (17.78%).

Wildlife attacks on livestock and poultry

A total of 768 wild animal attacks on livestock and poultry were reported in the study area. Among these cases, 734 attacks were on livestock, while 34 attacks occurred on poultry. The main culprits for attacks on livestock (79%) were gray wolves, Persian leopards (17%), and golden jackals (1%), respectively. In the case of attacks on poultry, golden jackals were responsible for the majority of the attacks (76%), followed by red foxes (24%) (χ^2=0.778, df=7, p-value > 0.05) (Online Resource 1: Fig. 2). The most casualties from these attacks

were domesticated sheep, with 1,760 individuals, followed by hens and roosters (139 individuals) and domesticated goats (132 individuals) (Online Resource 1: Fig. 3). The temporal distribution of carnivore attacks reveals that the highest number of attacks on livestock occurred during the summer of 2016, specifically at nighttime (Fig. 4). More than 90% (90.62%) of the attacks were reported to occur during the night, in contrast to only 9.38% of incidents that occurred during the daytime (χ^2=4.780, df=5, p-value>0.05). Significant seasonal variations in wildlife attacks on livestock and poultry occurred (χ^2=54.866, df=15, p-value=0), with 40.76% of them occurring in summer, followed by 33.59% and 14.58% for spring and autumn, respectively.

Damages caused by wild animals to agricultural crops

Regarding damages to orchards and farmlands cause by wild animals, 620 cases were reported in the study area. Among these cases, 90.2% were caused by wild boars, while Indian crested porcupines and golden jackals accounted for 9.4% and 0.5% of the cases, respectively (χ^2=7.111, df=4, p-value>0.05) (Online Resource 1: Fig. 4). Most of the damage was inflicted on fruit trees (such as apples, walnuts, and pears), wheat, vegetables, and alfalfa (Online Resource 1: Fig. 5). The highest number of attacks on orchards and farmlands occurred during in the summer of 2016, primarily during nighttime (Fig. 5). Conflicts were more likely to happen at night (78.36%) than during the daytime (21.64%) (χ^2=0.884, df=2, p-value>0.05). The highest damage cases were documented in summer (72.98%), followed by spring (21.25%) and autumn (5.7%), respectively (χ^2=0.958, df=4, p-value>0.05).

According to reports from the DEPs and residents, the total financial losses from wild animal attacks amounted to 9,258,285,000 Iranian Rials. Fruit trees accounted for the most significant damage, with a loss of 3,466,000,000 Iranian Rials, followed by wheat and rice with losses of 2,635,500,000 and 818,000,000 Iranian Rials, respectively.

Mapping human-wildlife conflict hotspots

We have conducted a hotspot analysis to identify areas with a higher likelihood of wildlife conflicts within the study area. The hotspots of wild animal attacks on humans were located

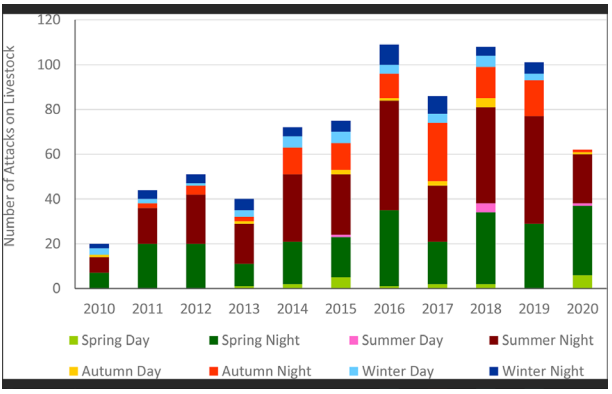

Fig. 4 Year, season and time of wild animals' attacks on livestock and poultry in the study area during spring 2010 to autumn 2020

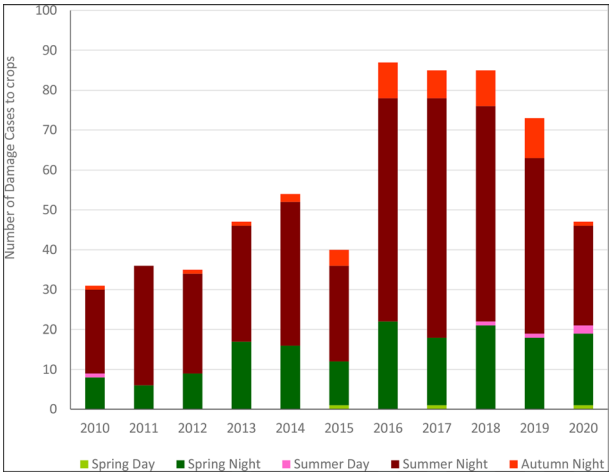

Fig. 5 Year, season and time of wild animals' damages to orchards and farmlands in the study area during spring 2010 to autumn 2020

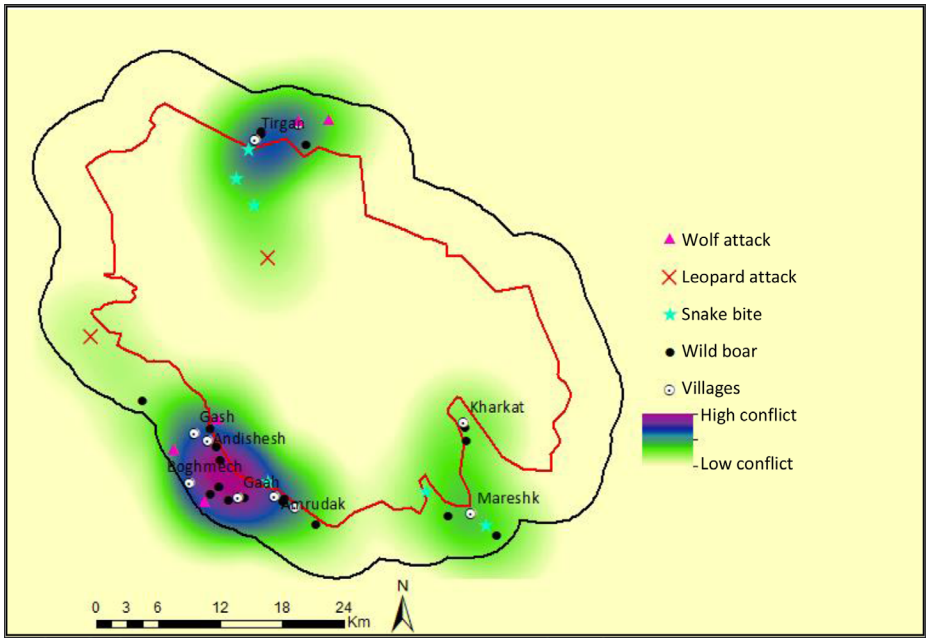

Fig. 6 Hotspot map of wild animals' attacks on human

within a 5 km buffer of the OSPA, primarily in the southern and northern parts of the area, as well as around the villages of Boghemch, Gaah, Tirgan, Polgerd, and Mareshk (Fig. 6).

The hotspot areas of wild animal attacks on livestock and poultry were mainly distributed inside the protected area in the north and south parts of the region (Fig. 7). Wolf attacks on livestock occurred inside and around the protected area, with a higher frequency inside. Hyena attacks on livestock occurred in pastures around the OSPA, mainly around Polgerd, Charam No, and Charam Kohneh. Fox and jackal attacks on poultry mostly occurred

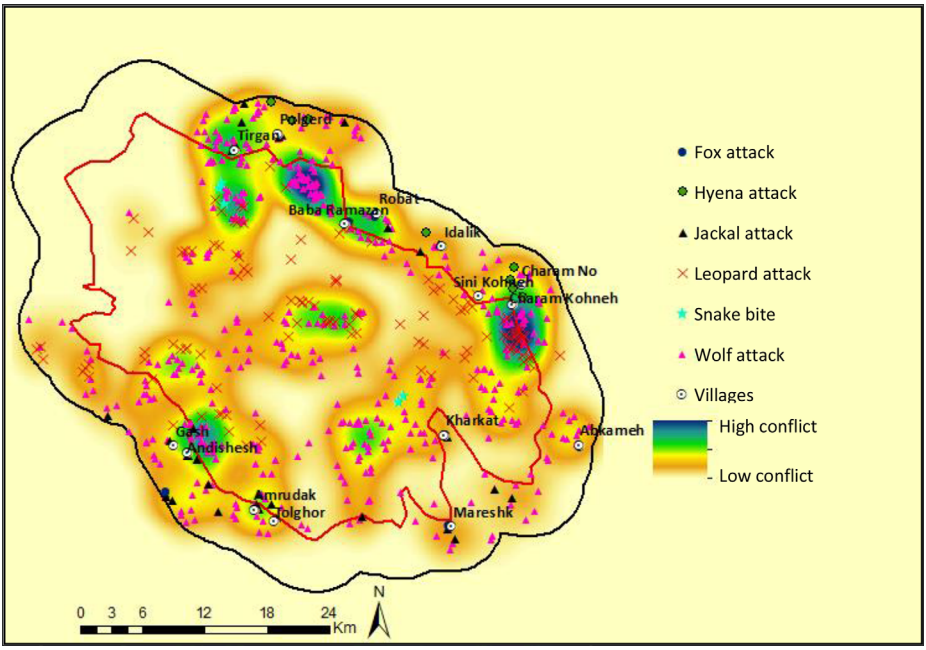

Fig. 7 Hotspot map of wild animals' attacks on livestock and poultry

within the villages, while jackal attacks on livestock occurred around the villages (Fig. 7). The hotspots for damage caused by wild animals to orchards and farmlands were primarily observed in the north, south and east parts of the study area, within the buffer zone around Tirgan, Polgerd, Robat, Idalik, Mareshk, Tolghor, Amrudak, Gaah, Boghmech, and Andishesh. (Fig. 8).

Discussion

People residing in the OSPA and its surrounding lands have experienced substantial human-wildlife conflicts caused by different species at varying spatial and temporal patterns. Human-wildlife conflict in this study was defined as species attacking humans and livestock and the damages occurring to crops. Most respondents reported attacks and damages caused by wildlife indicating that conflicts between humans and wild animals in the study area can be considered a severe issue. We found that the type of species, their diurnal or nocturnal characteristics, land-use type, and distribution of human settlements determine critical locations and occasions of conflicts (Constant et al. 2015). The hotspot maps highlight potential conflict zones for attacks and damages caused by different wild species influenced by land management and proximity to villages. The findings also indicate that there is an apparent temporal pattern in the variability of conflict potential related to grazing seasons in spring and summer, species' nocturnal behaviors and adaptations, and potential influences of human disturbances on wild species' temporal activities causing a higher number of attacks and damages during warm seasons and nights. Our findings suggest that a matrix of natural

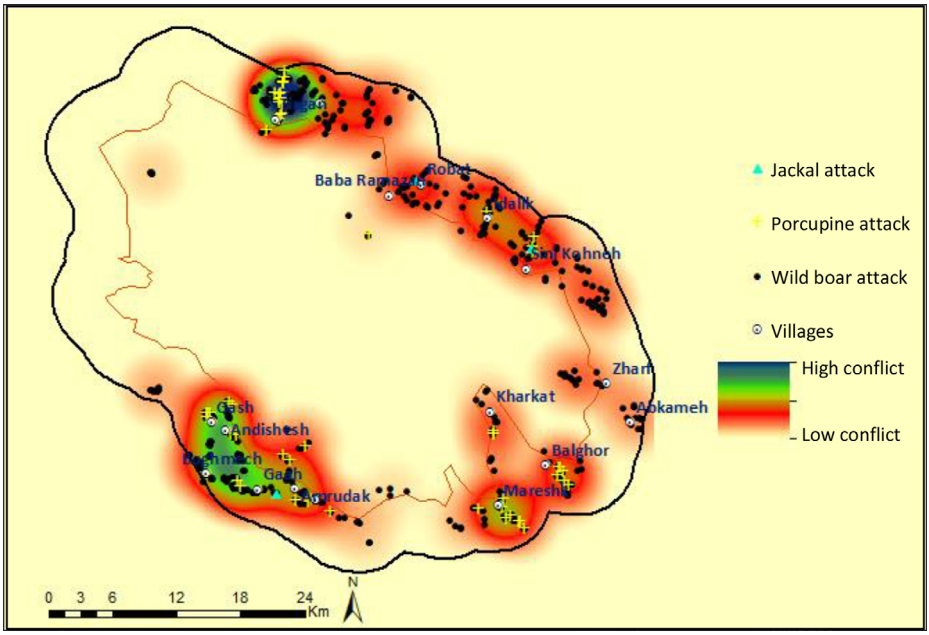

Fig. 8 Hotspot map of damages caused by wild animals to orchards and farmlands

and human-dominated landscapes can provide a home for relatively more adaptable species (Rodewald and Gehrt 2014), showing more tolerance to human-mediated disturbances (Srivastava et al. 2020).

Spatial and temporal patterns of attacks on humans

In our study area, wild boars were the most detrimental wild species for humans. Wild boars' attacks on humans have been documented since ancient times; however, no studies have mainly investigated these incidents. Although wild boars do generally not attack humans and often escape when exposed to them, they have the potential to injure humans (Mayer 2013) with intense and frequent movements and sharp teeth (Gunduz et al. 2007). Night irrigation of orchards and farmlands, as well as low visibility in the dark, are factors that cause unintended exposure of humans to wild boars, resulting in situations where the animal attacks as it feels threatened without any way to escape (Mayer 2013), which can provoke the animal and result in attacks on humans.

Humans are not the natural prey for carnivores such as wolves and leopards. Therefore, the few attacks they make on humans are often due to people's lack of knowledge about the species' behavior and the appropriate response in case of an unexpected encounter in nature. Injuries to wolves and leopards by humans or herding dogs can also provoke them to attack humans. Humans' occupation of their natural habitats and converting them to pastures or agricultural lands increases the possibility of unwanted human encounters with these species. The non-fatal attacks of leopards in this study can support the idea that the attacks were more defensive rather than predatory (Kshettry et al. 2017). One strategythat seems suc-

cessful in reducing the number of human casualties is warning the leopards before human presence in the high conflict areas allowing them to move away from the shared space.

Spatial and temporal patterns of attacks on livestock

We have discovered that gray wolves, accounting for over 75% of livestock attacks, are considered the most detrimental species to livestock including goats, sheep, and poultry. This observation can be attributed to the larger wolf population in the area compared to the leopard population. According to the DEPs' conservation officers, the wolf population in OSPA during warm seasons is estimated to be more than four times that of leopards, ranging from approximately 70 to 90 individuals for wolves, compared to 15 to 20 individuals for leopards.

Gray wolves are widely distributed in various parts of Iran and have received particular attention due to increased conflicts with local communities in recent years (Behdarvand et al. 2013). Based on existing reports by Abdollahi et al. (2012) also indicate that wolves were identified as the most detrimental wild species to livestock in Iran. Previous studies on wolf feeding habits in human-dominated landscapes reported that domestic ungulates, primarily goats and sheep, are the primary prey of wolves in Greece, Spain, and Italy (Ciucci et al. 2018; Lagos & Bárcena 2018; Petridou et al. 2019). The grazing behavior of goats in denser areas and steeper terrains increases their encounters with wolves, which prefer these areas for resting and establishing their dens (Llaneza et al. 2016; Sazatornil et al. 2016). On the other hand, sheep were found to be less preferred by wolves, likely due to their grazing in open pasture areas in compact flocks, making them a more challenging target (Torres et al. 2015; Petridou et al. 2019). The higher sheep mortality in our study could be attributed to the more extensive number of sheep villagers keep than goat populations. According to our social survey, the number of sheep (16,904 individuals) held by respondents was 12 times greater than the number of goats (1364 individuals) in the last year of the study period, 2020.

Other factors may contribute to many conflicts between wolves and livestock. Habitat destruction, land-use changes (Tajbakhsh et al. 2020; Makindi et al. 2014), and the illegal hunting of wild goats and sheep by poachers leading to a decrease in the natural prey population for large carnivores like wolves (Soofi 2017) can be considered as significant triggers for wolf attacks on livestock. Furthermore, other factors such as excessive livestock grazing in pastures, the insecurity of some livestock pens in villages and nomadic regions, and the limited experience of some shepherds in livestock herd care (Farhadinia et al. 2019) can also increase the incidence of wolf attacks on livestock and resulting mortalities.

This study identified leopards as the second most detrimental carnivores to livestock. This finding aligns with Abdollahi's research, which classified leopards as the second most detrimental wild species in Iran, following gray wolves. The significant proportion of leopard attacks on livestock may be attributed to their flexible feeding habits and ability to persist in areas with low availability of wild prey by resorting to domestic animals as a food source (Athreya et al. 2013; Odden et al. 2014). It has also been reported that leopards reduce their home range when occupying areas with high human population density and focus on domestic animals for feeding due to the low abundance of wild ungulate species (Odden et al. 2014). Given their high adaptability to humans, understanding leopard-human interactions is crucial to for minimizing conflicts with local communities (Odden et al. 2014; Woodroffe et al. 2005). Another factor contributing to the increase in leopard attacks

on livestock and dogs is the illegal hunting of wild sheep and goats, as these animals are the primary natural prey of leopards (Farhadinia et al. 2019).

The hotspot map of wild animal attacks on livestock reveals that most leopard attacks occurred in the pastures inside the protected area. Traditional ranching and the heavy reliance of ranchers inside and around OSPA on these pastures are likely the most crucial factors contributing to the leopard attacks on livestock. The permitted grazing period within the OSPA begins in early June and lasts until early August each year. However, due to the scarcity of forage in the pastures surrounding the protected area and the high feed cost, some ranchers exceed the allowed time and continue using the OSPA rangelands.

Other nearby livestock and poultry predators are Jackals, hyenas and foxes around the villages. Jackals and foxes primarily target poultry inside the villages, particularly at night. As birds, reptiles, and small mammals serve as familiar food sources for small carnivores (Karami et al. 2016), herding or stray dogs in the area's pastures can decrease the population of small prey species. Consequently, smaller wild carnivores may resort to livestock and poultry as alternative food sources. Seasonal variations also play a role, as jackals and foxes can hunt small mammals, rodents, reptiles, and birds in their natural habitats during spring and summer. However, during seasons with little natural prey, such as autumn, they approach villages and their surroundings to hunt poultry. This finding aligns with other studies that indicate small carnivores are generally tolerant of human-mediated disturbances. For instance, red foxes (Ghoshal et al. 2016), spotted hyenas (Abay et al. 2011), and golden jackals (Yom-Tov et al. 1995) have been observed to rely on human-provided resources in semi-rural to urban landscapes.

Assessing the temporal distribution of livestock losses reveals that most losses in the study area occur in summer and spring. Abundant vegetation during these seasons causes herds to be more dispersed within the protected area. Additionally, the presence of vulnerable individuals, such as lambs, within the herds increases the frequency of predator attacks. Consequently, ranchers and wildlife managers should devise and implement strategies to mitigate attacks during these seasons. Since the pastures inside the protected area are not utilized in the colder seasons of autumn and winter, the rate of livestock attacks was lower compared to warmer seasons. During autumn and winter, predators often venture into pastures near villages, livestock graze or approach pens near human settlements, increasing the risk of encountering herding dogs and rural communities. Throughout the study period, livestock attacks and resulting mortalities were more frequent at night than during the day by the natural hunting behavior of primarily nocturnal predators, who typically pursue their prey in the early morning or evening. Furthermore, the higher level of livestock mortalities at night can also support the argument of previous studies (e.g. Gaynor et al. 2018; Odden et al. 2014) regarding the increased nocturnal activity of mammal species in human-dominated landscapes. Therefore, it is essential to consider necessary measures for effectively addressing this issue in the study area's management plan. Ranchers and rural communities should also receive training to safeguard their livestock during nighttime.

Spatial and temporal patterns of damages to agricultural crops

Wild boars were identified as the most destructive wild species for orchards and farmlands. This finding is consistent with the results reported by Abdollahi et al. (2012), which identified wild boars as the most damaging species to the agriculture sector in most regions of

Iran. Fruit trees, rainfed wheat, and rice suffered the most significant financial losses in this sector due to these damages. As one of the most prevalent species in Iran, wild boar the population of wild boars has increased in various parts of the country due to factors such as their omnivorous diet, high reproduction rates, and religious beliefs preventing hunting, leading to severe damages in orchards and farmlands (Rezaei 2016). A temporal evaluation of their attacks indicates that most damage caused by wild boars to orchards and farmlands occurs during the summer and spring season, which is consistent with the results of Rezaei (2016). We also discovered that most wild boar damage to farmlands and orchards transpires at night which aligns with the findings of Ikeda et al. (2019). Vegetation richness in the natural habitats of wild boars can provide them with ample food sources, reducing the intensity of their attacks on crops and subsequent damages (Bobek et al. 2017). However, due to the utilization of pastures inside and around the OSPA and for livestock grazing in most seasons, the scarcity of vegetation in the species' natural habitats and inadequate food sources compelled them to invade orchards and farms, thereby exacerbating the conflict. The presence of abundant water resources, suitable lands, and subsequent agricultural prosperity in these areas can be considered the main factors contributing to higher crop damage in these regions.

Implications for managing human-wildlife conflict

Based on the findings of this study, the identified conflict hotspots and temporal clustering of attacks can serve as excellent opportunities to implement conservation measures that mitigate conflicts with various species in the Ors-e-Sistan protected area. Wildlife species, includinglarge carnivores, have extensive habitats. Coexistencewith humans is inevitable, particularly in human-dominated landscapes. However, this circumstance can result in property damage and attacks on humans (Jhamvar-Shingote & Schuett 2013). Thus, it emphasizes the importance of managing human-wildlife conflicts to adverse impacts on human lives and to support conservation goals.

In this situation, rural communities' lack of knowledge or limited use of efficient methods to prevent wild animal attacks, such as pens or indoor and safe areas for keeping livestock and poultry, can be one of the factors underlying wild carnivores' attacks on them (Farhadinia et al. 2019). Hence, the first step in preventing conflicts with wild animals, particularly carnivores, is to inform people residing in high-conflict areas about the causes and roots of the conflict events to empower them for proper conflict management. Preventive strategies, such as the use of well-trained shepherds and livestock-guardian dogs, have been identified as successful in reducing the attacks of wild animals (Constant et al. 2015).

Another reasons for using inappropriate places for keeping livestock is the cost and unaffordability of safe and well-equipped areas. Living in nomadic conditions where simple structures are used for pens increases livestock losses. Most of the carnivore attacks on livestock took place inside the protected area. This indicates that livestock's use of pastures inside the area and their interference with wildlife habitat can be another significant cause of livestock losses. Proper management of grazing time, assessing pasture capacity, and using alternative methods such as centralized livestock ranching that reduce the dependence on grazing within the protected area can play a crucial role in reducing livestock losses and effectively dealing with existing conflicts. The results show that the trend of attacks on livestock in the study area has been increasing over ten years, which needs further exami-

nation by authorities to determine the role of underlying factors influencing the increase in attacks. These factors could include climate change, the decrease in the population of wild herbivores as wild prey, the increase in the illegal hunting of natural prey by humans, the increase in livestock predation due to diseases, and the increase livestock entry into the protected area.

Conclusion

In this study, we demonstrate spatial and temporal patterns of human-wildlife conflicts, which can provide valuable insights for managing and mitigating these issues and pave the way for assessing the drivers of such conflicts across a landscape. Our study reveals that priority areas and critical times for managing human-wildlife conflicts are influenced by a wide range of species-specific and human-related factors in the context of protected areas. The temporal patterns and spatial locations identified as high-conflict areas should be prioritized in human-wildlife conflict management programs, along with increasing the awareness of rural communities regarding the characteristics of wildlife species and the patterns of their attacks (Karimi and Adams 2019). The findings emphasize the importance of local knowledge and understanding people's perceptions and expectations for developing appropriate conflict mitigation strategies.

Additionally, our findings support wild mammals' significant flexibility exhibited by in utilizing natural and human-modified habitats (Srivastava et al. 2020). Future studies should evaluate spatio-temporal patterns of wild animal populations to comprehend their tolerance of human presence in space and time, thereby avoiding direct encounters with humans. Temporal assessments of carnivore and wild prey populations are necessary to investigate prey-predator relationships. Moreover, it is crucial to identify the relationships between existing conflict areas and environmental drivers understand conflict distribution better and develop effective conflict mitigation strategies (Sharma et al. 2020).

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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