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Livestock predation patterns by gray wolves and persian leopards in Iran

Jamshid Parchizadeh[1]✉, Mariano G. Arias[2] & Jerrold L. Belant[1]

Large carnivore species frequently predate and consume wild or domestic prey, which is referred to as food-related predation. Large carnivores can also hunt and kill prey exceeding their immediate needs (i.e., they do not consume prey), which is referred to as surplus predation. We used 173 records of livestock predations by gray wolves (*Canis lupus*; *n* = 133) and Persian leopards (*Panthera pardus tulliana*; *n* = 40) reported by governmental organizations of Iran during 2009–2019 to investigate food-related and surplus predation incidents of livestock. We found that for wolves, the number of reported surplus predation incidents was greater than that of food-related predation incidents during all 4 seasons (spring through winter), whereas for leopards, the number of food-related and surplus predation incidents were similar in all seasons. The number of livestock killed per surplus predation incident was greater for wolves than for leopards and that surplus predations by both species occurred more frequently within corrals than on free-range pastures. As corrals in most villages across Iran are poorly constructed and largely accessible to predators, we recommend that livestock owners enhance corral construction, use well-trained dogs during day and particularly at night, employ people to watch livestock at night, and use fire (e.g., torches) during night to scare carnivores. These strategies can mitigate predation incidents and corresponding economic losses, resulting in fewer losses of livestock, wolves, and leopards, as these two carnivore species are mainly killed by humans due to livestock predations across Iran.

Keywords *Canis lupus*, Gray wolf, Livestock, *Panthera pardus tulliana*, Persian leopard, Predation

Free-ranging large carnivores hunt, kill, and consume other organisms for sustenance[1]. Large carnivores often consume most or all consumable portions of prey killed (hereafter food-related predation[2]), and sometimes consume little or no parts of prey killed (hereafter surplus predation[3,4]). Surplus predation behavior may occur in response to a superabundance of prey[5] or a lack of inhibition from satiation given circumstances in which searching, hunting, and predation are easy[6]. Large carnivores exhibit surplus predation of wild prey (e.g., spotted hyena [*Crocuta crocuta*] on Thomson's gazelle [*Gazella thomsonii*][6]; jaguar [*Panthera onca*] on olive ridley turtles [*Lepidochelys olivace*][4]) and livestock species (e.g., puma [*Puma concolor*] and lion [*Panthera leo*] on cattle, sheep, goats, and pigs[6]. Surplus predation of livestock can reinforce negative attitudes of humans towards large carnivores, resulting in retaliatory killing of carnivores, with long term conservation consequences[6,7]. Consequently, it is important to understand patterns of surplus predation of livestock by large carnivores to mitigate conflicts between livestock owners and carnivores, which in turn can improve their management and human-carnivore coexistence[8].

Gray wolves (*Canis lupus*) and leopards (*Panthera pardus*) are frequently involved in surplus predation of livestock[6,9,10], which can account for a large percentage of total livestock losses[11]. Leopards are solitary carnivores that hunt and kill as individuals[12], whereas wolves are social carnivores[13] which often hunt and kill in packs[14]. Wolves frequently kill higher numbers of livestock per incident than do leopards[6,11]. For instance, individual leopards killed up to 22 sheep during separate incidents[15], whereas a pack of wolves killed up to 60 sheep in a single incident[11].

Livestock species are more susceptible to surplus predation when confined and in a corral[16,17]. Large carnivores often enter poorly constructed corrals where they have access to livestock that cannot escape[18,19]. This can result in greater livestock mortality compared to that of free-ranging livestock[20,21]. For instance, an individual leopard entered a poorly constructed corral and exhibited surplus predation of 37 goats[22]. Similarly, a pack of wolves entered a poorly constructed corral and exhibited surplus predation of up to 300 sheep[23].

[1]Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824, USA. [2]Department of Environmental and Forest Biology, SUNY ESF, Syracuse, NY 13210, USA. ✉email: Jamshid.Parchizadeh@gmail.com

We investigated patterns of food-related and surplus incidents of livestock predation by gray wolves (hereafter wolf) and Persian leopards (*P. p. tulliana*[24]; hereafter leopard) across Iran. We hypothesized that wolves and leopards would be predisposed toward surplus predation of livestock[1,6,9,10]. Specifically, we predicted that for each carnivore species, the number of surplus predation incidents would be greater than that of food-related predation incidents in all 4 seasons (spring, summer, autumn, and winter) since wolves and leopards are frequently involved in surplus predation of livestock year-round[1,6,9,10]. We also predicted that the number of livestock killed per surplus predation incident would be greater for wolves than that of leopards since wolves often hunt and kill in packs, whereas leopards are solitary predators that hunt and kill as individuals[6,11,12,14,19]. We further predicted that surplus predations would occur more frequently within corrals than on free-range pastures since these predators can have access to livestock that cannot escape[10,16–19].

Materials and methods

Study area

Iran comprises 1,648,195 km^2 in southwestern Asia (25–40°N, 44–64°E) containing 31 provinces (Fig. 1). Major mountain ranges include the Alborz and Zagros which occur across the northern and western parts of Iran, respectively[25]. Elevations range from 28 m below sea level to 5,610 m above sea level[26]. The climate is continental with hot, dry summers and cold winters. Mean monthly temperatures range from 7.5 °C in January to 33 °C in July[27]. Annual precipitation decreases from 1800 mm in the north to < 100 mm in central arid regions[28].

Traditional animal husbandry practices are common in rural regions across Iran where livestock husbandry is an important source of income for local communities[29,30]. Large herds of livestock graze on free-range pastures, mainly under the care of young males (< 15-years old) sometimes accompanied by untrained guard dogs (i.e., dogs are unable to deter wolves and leopards[31]). Livestock are kept in covered corrals at night, either in villages or on free-range pastures[31]. Corral walls are commonly built of mud or low height stone and woven plastic bags are commonly used as roofs and doors[32].

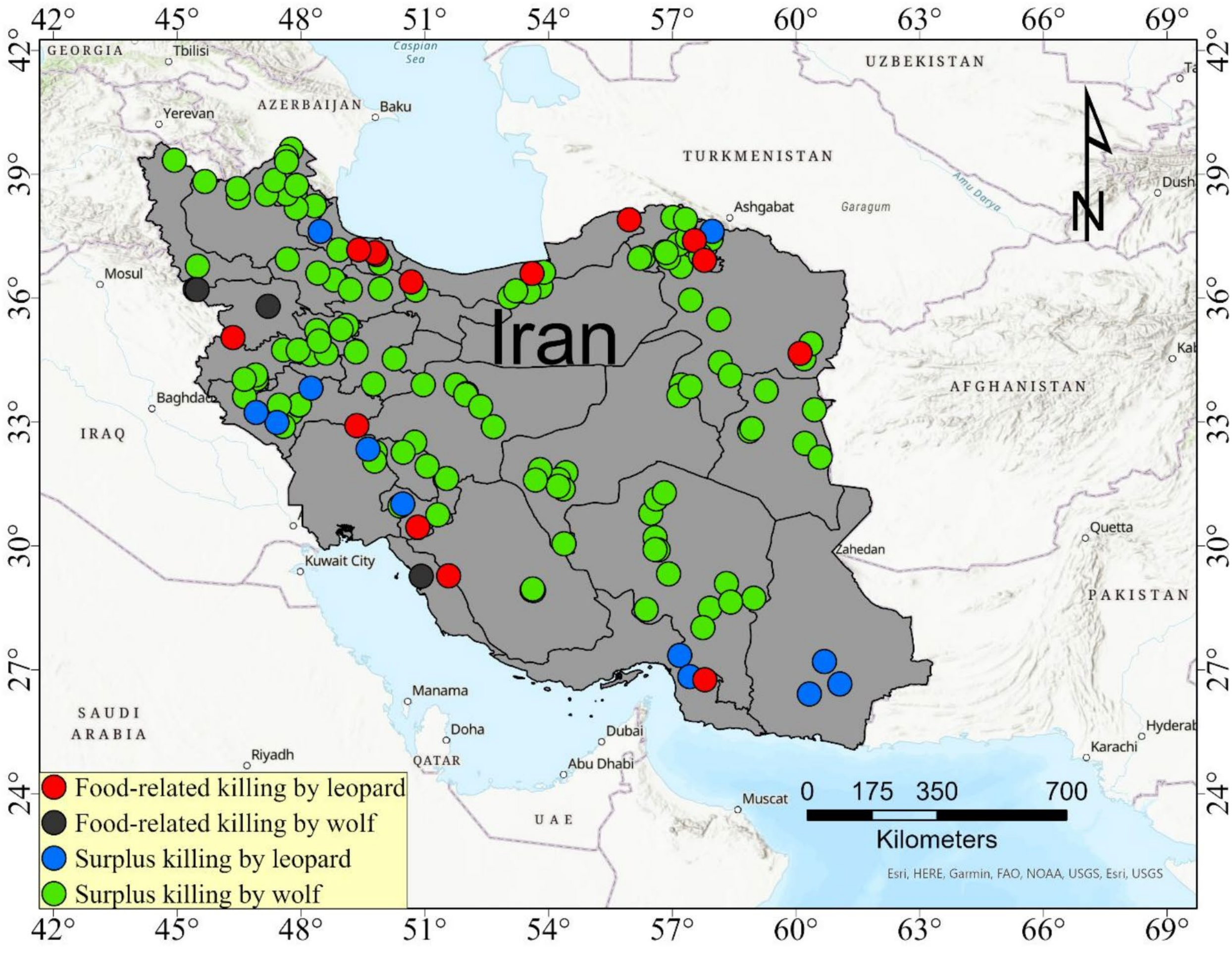

Fig. 1. Locations of reported food-related and surplus predation incidents of livestock by gray wolves (*Canis lupus*) and Persian leopards (*Panthera pardus tulliana*), Iran, 2009–2019. Map was created using ESRI ArcGIS Pro Version 3.0.3 (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

Data collection and analysis

We used records of livestock predations by wolves and leopards reported by Local, Regional, and Provincial offices of Iran's Nomadic Affairs Organization, Ministry of Agriculture Jihad, and local or regional units of Iran's Ministry of Interior (i.e., rural district management, county management, local or regional police) during 2009–2019. Livestock owners whose animals were killed by wolves or leopards, submitted complaints to the respective offices to be eligible for economic compensation. Experts of the relevant Local, Regional, or Provincial offices of Iran's Department of the Environment visited the incident scene for inspection and verification. To visually identify carnivore species responsible for livestock predation, images of carnivores present in the area were shown to livestock owners or people who witnessed the incident[33]. Department of Environment experts evaluated the reliability of reports based on evidence described by respondents including carnivore tracks left near the predation site; signs of struggle; and drag, claw, or bite marks on livestock throats or necks[34]. After verification, the following were recorded for each incident: (i) carnivore species (wolf or leopard) and livestock species (cow, goat, or sheep) involved, (ii) number of livestock killed, (iii) whether the incident occurred within a corral or on a free-range pasture, (iv) if within a corral, local name of the place or village name, (v) if on a free-range pasture, local place name or approximate distance and direction from the nearest village, (vi) province, and (vii) date of incident.

We used the Iranian calendar to define seasons as winter (21 December–20 March), spring (21 March–20 June), summer (21 June–20 September) and autumn (21 September–20 December)[35]. We defined incidents where one livestock was killed and consumed by a wolf or leopard as food-related predation, and incidents where ≥ 2 livestock were killed but not consumed entirely as surplus predation[36]. We used physical descriptions of each incident in reports to estimate their geographic location (typically within 5 km[37]).

We tested the number of food-related predation incidents against the number of surplus predation incidents for each carnivore species using two-way χ^2 tests. We also compared the total number of surplus predation incidents within corrals to that of free-range pastures, using two-way χ^2 tests, and the number of surplus predation incidents across seasons (spring, summer, autumn, and winter) for each species using the same statistical method. We fit linear models using the function *lm* to contrast the number of livestock killed by each carnivore species during surplus predation incidents, adjusting by livestock species. We used the total number of livestock killed (all prey species pooled) as our response variable, and predator and livestock species as our covariates. We conducted all analyses in the statistical environment R version 4.1.1[38] and used $\alpha < 0.05$ to denote statistical significance.

Results

We compiled 173 reported incidents of livestock predation by wolves ($n = 133$) and leopards ($n = 40$). Food-related predation incidents by leopards occurred more frequently in northern Iran, whereas surplus predation incidents occurred more often in the west and south (Fig. 1, Table S1). Surplus predation incidents by wolves occurred throughout the country.

Wolves and leopards primarily targeted sheep ($n = 125$, and $n = 24$ incidents, respectively), followed by cows ($n = 5$, and $n = 10$ incidents, respectively), and goats ($n = 3$, and $n = 6$ incidents, respectively). Food-related and surplus predation incidents occurred within corrals ($n = 109$ by wolves, $n = 37$ by leopards) and on free-range pastures ($n = 24$ by wolves, $n = 3$ by leopards).

Wolves were more frequently involved in surplus predation incidents ($n = 126$) than in food-related predations ($n = 7$) ($\chi^2 = 106.47$, df = 1, $p < 0.01$), whereas leopards were similarly involved in food-related ($n = 21$) and surplus predation incidents ($n = 19$) ($\chi^2 = 0.1$, df = 1, $p = 0.75$). Surplus predation incidents involving wolves were more frequent than food-related predation incidents in all 4 seasons ($n = 133$) ($\chi^2 = 138.7$, df = 7, $p < 0.01$), but there was no difference between the number of food-related and surplus predation incidents for leopards across seasons ($n = 40$) ($\chi^2 = 7.2$, df = 7, $p = 0.40$). Wolves killed a greater number of livestock in surplus predation incidents than leopards ($F_{1, 142} = 43.00$, $p < 0.01$), killing per surplus incident an average of $\bar{x} = 6.5$ (± 0.2 standard error [SE]), and $\bar{x} = 2.0$ (± 0.0 SE) prey, respectively. Livestock species had no effect on the number of prey killed per incident ($F_{2, 142} = 0.12$, $p = 0.72$). Surplus predations occurred more frequently within corrals ($n = 102$ by wolves, $n = 19$ by leopards), compared to free-range pastures ($n = 24$; wolves only) ($\chi^2 = 64.89$, df = 1, $p < 0.01$).

Discussion

Our predictions of livestock predation patterns by wolves and leopards across Iran were partially supported. Contrary to our prediction, our findings revealed that the number of surplus predations was greater than that of food-related predations in all 4 seasons only for wolves, but not for leopards. For wolves this was probably a consequence of this carnivore killing prey in excess of their immediate food needs[39]. Wolves often target a greater number of wild prey and livestock species than they can consume[9,40]. For instance, wolves were involved in surplus predation of 34 barren-ground caribou (*Rangifer tarandus groenlandicus*) calves, of which 17 carcasses were not consumed and the remaining 17 partially consumed[41]. Wolves in Scandinavia were reported to kill more than three times the biomass of moose (*Alces alces*) required to sustain their metabolic rate[42]. Similarly, a pack of wolves was involved in five surplus predation incidents of sheep, resulting in mortality of over 20 sheep per incident, none of which were consumed[40]. In Iran, wolves were responsible for surplus predation of > 10 sheep and goats per incident[43]. Surplus predation incidents have been reported for other large carnivores; snow leopards (*Panthera uncia*) and dingoes (*Canis familiaris dingo*) killed sheep and goats, respectively, in excess of their nutritional requirements[44,45]. Furthermore, though leopards frequently exhibit surplus predation of livestock species (e.g.[15,22,46]), previous studies in Iran[47,48] concluded that leopards mainly avoided livestock species predation. We found that leopards were similarly involved in food-related and surplus predation incidents, likely due to limited opportunity to exhibit surplus predation (e.g., livestock owner arrival[49]).

Our results showed that the number of livestock killed per surplus predation incident was greater for wolves than that of leopards, which was likely linked to different social structures of these carnivore species. Leopards are solitary predators that hunt and kill as individuals[12], whereas wolves are social carnivores that live in cohesive packs[13]. This social dynamic enables wolves to coordinate hunts and engage in collective predation incidents[14], which can result in a greater number of livestock mortalities per incident[6,11]. A pack of wolves in a single incident can kill four to six times more sheep and cattle compared to solitary brown bears (*Ursus arctos*)[11]. Similarly, cooperative group behavior among dingoes led to a greater number of sheep mortalities per incident compared to solitary dingoes[44].

We found that wolves and leopards were more often involved in surplus predations within corrals than on free-range pastures, likely a result of poor corral construction. Surplus predation of livestock by large carnivores is a common phenomenon, particularly for animals housed in inadequately structured corrals and during night[3,50,51]. Corrals with deficient construction, such as low height or no roof, can facilitate entry by large carnivores[45,52]. Individual leopards on separate occasions killed 22 sheep and 37 goats each when they breached vulnerable corrals[15,22]. Similarly, a wolf and a pair of snow leopards killed up to 300 and 70 sheep, respectively, after entering accessible corrals[23,53,54]. Corrals in most villages across Iran lack essential features including sturdy doors, walls, windows, and roofs, with makeshift coverings like woven plastic bags serving as substitutes. We recommend that livestock owners enhance corral security by installing secure doors, windows, roofs, and constructing durable walls to reduce accessibility by large carnivores, consequently reducing the incidence of livestock predation[55]. Furthermore, employing people to watch livestock at night[56], the presence of well-trained dogs alongside livestock during day and particularly during night[17], and use of fire (e.g., torches) at night to scare carnivores[56] may provide additional protection to further mitigate livestock risk.

Livestock predation by large carnivores is a major global conservation challenge[55]. Developing effective mitigation measures to reduce these incidents is crucial for successful conservation of large carnivores and fostering conditions conducive for coexistence with humans[7]. While large carnivores typically kill livestock for food[2,57], there are instances where they exceed this need[3]. Wolves and leopards are frequently implicated in surplus predation incidents of livestock, which can exacerbate human intolerance towards these carnivores[36,39], and may increase human-caused mortality[10]. In Iran, wolves and leopards are frequently killed by humans due to livestock predation incidents[10]. Positive human attitudes toward carnivores are correlated with less economic loss in carnivore-induced losses (i.e., livestock predation)[58,59]. The Iranian government is responsible for compensating the losses of livestock to large carnivores including wolves and leopards[60]. However, due to limited financial resources and increased livestock predation incidents by carnivores, the compensation programs are less effective than they could be[60]. Though rules are defined to the conflicts between livestock owners and carnivores through compensation programs to improve the attitudes of local communities, these rules are not fully implemented since payments are not often made, or are slow to process (e.g., substantial paperwork among multiple governmental organizations), and compensation is often only partially realized[60]. Consequently, a large number of livestock predation incidents may not be reported to authorities[61], which in turn suggests conflicts between livestock owners and carnivores are greater than reported. Allocating budgets and streamlining compensation processes to local communities who lose livestock to wolves and leopards can improve attitudes toward carnivores and reduce future conflicts[10]. We also recognize the potential role of livestock owners in conservation efforts toward wolves and leopards. By implementing effective strategies including more secure corrals, people watching at night, and well-trained guard dogs, livestock owners can reduce carnivore access to livestock[17,56]. These strategies can reduce economic losses from predation incidents[62–64], resulting in fewer losses of livestock, wolves, and leopards.

Data availability

Data is provided within a supplementary information file.

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Author contributions
J.P. and M.G.A. and J.L.B. wrote the main manuscript text. M.G.A. conducted statistical analyses. J.P. prepared Fig. 1. J.L.B. supervised the manuscript. All authors reviewed the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
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Correspondence and requests for materials should be addressed to J.P.

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