

## The relationship between climate, diseases of domestic animals and human-carnivore conflicts



Igor Khorozyan<sup>a,\*</sup>, Mahmood Soofi<sup>b,1</sup>, Arash Ghoddousi<sup>a</sup>,  
Amirhossein Khaleghi Hamidi<sup>b</sup>, Matthias Waltert<sup>a</sup>

<sup>a</sup>Workgroup on Endangered Species, J.F. Blumenbach Institute of Zoology and Anthropology, Georg-August University of Göttingen, Bürgerstrasse 50, Göttingen 37073, Germany

<sup>b</sup>Persian Wildlife Heritage Foundation, 99 Karimkhan Avenue, Tehran, Iran

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### Abstract

Human-carnivore conflicts over livestock predation threaten biodiversity conservation and rural development, but the impact of climate and its change on such conflicts is insufficiently studied. The effect of climatic factors on diseases of predation-prone domestic animals and then on conflicts is unstudied, but potentially significant. This empirical case study addressed the conflict between people and leopards (*Panthera pardus*) in the Hyrcanian humid temperate forest (Iran). We analyzed our questionnaire and other data from all 34 villages around Golestan National Park in terms of probabilities of human-leopard conflicts over livestock predation, diseases of domestic animals and WorldClim bioclimatic variables. Using multiple predictive modeling approaches (generalized linear modeling GLM, Multivariate Adaptive Regression Splines MARS, Bayesian Belief Network BBN, BIOCLIM and DOMAIN), we show that climate continentality and precipitation patterns affect diseases, and more diseases lead to more conflicts. The Community Climate System Model (CCSM4) scenarios forecast aridization of the study area in 2041–2080 and a resultant decline of disease and conflict probabilities by 18.4–21.4% and 10.4–11.9%, respectively. We conclude that diseases can drive human-carnivore conflicts which may become less intense with projected aridization of the studied humid environment.

### Zusammenfassung

Konflikte zwischen Mensch und Raubtieren, die auf Prädation von Nutztieren basieren, stellen eine Bedrohung für den Schutz der Biodiversität sowie der ruralen Entwicklung dar. Einflüsse des Klimas und seines Wandels auf diese Systeme sind bisher nur unzureichend untersucht. Speziell der Einfluß klimabedingter Faktoren auf Krankheiten prädatationsanfälliger Tiere und damit zusammenhängende Konflikte sind bisher nicht untersucht, aber potentiell von großer Bedeutung. Die vorliegende empirische Fall-Studie beschäftigt sich mit dem Konflikt zwischen Mensch und Leopard (*Panthera pardus*) in hyrcanischen humid-temperaten Wäldern (Iran). Wir untersuchten Datensätze aus eigenen Fragebögen und anderen Quellen von allen 34 Dörfern um den Golestan Nationalpark in Hinblick auf auf Prädation von Nutztieren beruhenden Mensch-Leopard Konflikten,

\*Corresponding author. Tel.: +49 176 84831401; fax: +49 551 399234.

E-mail address: [igor.khorozyan@biologie.uni-goettingen.de](mailto:igor.khorozyan@biologie.uni-goettingen.de) (I. Khorozyan).

<sup>1</sup>Workgroup on Endangered Species, J.F. Blumenbach Institute of Zoology and Anthropology, Georg-August University of Göttingen, Bürgerstrasse 50, Göttingen 37073, Germany.

Nutztier-Krankheiten sowie WorldClim bioklimatische Variablen. Wir zeigen hier unter Anwendung verschiedener prädiktiver Modellierungsansätze (verallgemeinerte lineare Modelle GLM, multivariate geglättete Regressionen MARS, Bayesian Belief Network BBN, BIOCLIM und DOMAIN), daß Klima-Kontinentalität und Niederschlagsmuster Krankheiten beeinflussen, wobei zunehmende Krankheiten zu mehr Konflikten führen. Szenarien des Community Climate System Modells CCSM4 sagen eine zunehmende Aridifizierung für das Untersuchungsgebiet im Zeitraum 2041–2080 voraus und einen daraus resultierenden Rückgang der Wahrscheinlichkeit von Krankheiten und Konflikten um 18.4–21.4% bzw. 10.4–11.9%. Wir schlussfolgern, daß Krankheiten Mensch-Raubtier-Konflikte beeinflussen können und daß diese mit künftiger Aridifizierung der von uns untersuchten humiden Region abnehmen könnten.

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**Keywords:** Climate; Conflict; Disease; Golestan; Iran; Leopard; Livestock; Model; *Panthera pardus*

## Introduction

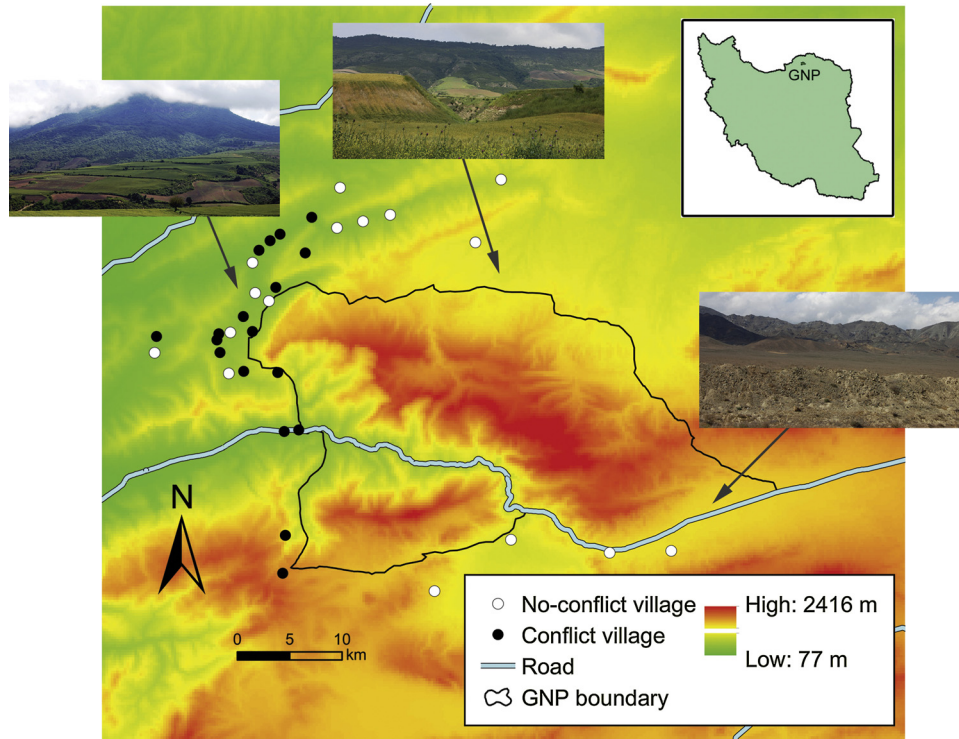
Climate affects all aspects of biodiversity, from individual fitness to ecosystem functioning (Sheridan & Bickford, 2011). Particularly, in terrestrial mammalian carnivores climatic conditions make a dramatic influence on body and tooth size variation (Sheridan & Bickford, 2011; Szuma, 2008), distribution (Abade, Macdonald, & Dickman, 2014; Tórrés et al., 2012), population size (Trinkel, 2013), speciation (Mukherjee et al., 2010) and faunistic evolutionary turnover (Meehan & Martin, 2003). As climate changes, carnivores can influence other species and communities by top-down regulatory processes, such as trophic cascades, for example by boosting vegetation growth through suppressing herbivores (Ripple et al., 2014). Also, predation risk creates the “ecology of fear”, which affects the behavior of ungulates and thus shapes the structure of ungulate and vegetation communities (Ripple et al., 2014). Due to their high mobility and tolerance to habitat characteristics, carnivores are most able to keep pace with climate change and even expand their ranges by occupying new favorable habitats and prey-rich areas (Kashkarov, Baranov, Pomortsev, & Ishchenko, 2008; Schloss, Nuñez, & Lawler, 2012). On the other hand, mountain-dwelling carnivores are prone to extinction because of the range shrinkage resulting from warming-triggered landscape and prey changes (Forrest et al., 2012). The same is expected to happen also with carnivores from maritime lowlands, where warming can lead to floods by raising sea level and increasing snowmelt rates at higher elevations (Seidensticker, 2008). Precipitation of the driest quarter has been the main determinant of the existence of carnivores in humid tropical forests, making their extinction imminent with increased seasonality and aridization (Wilting et al., 2010). Arctic biodiversity and particularly its top-level carnivores are extremely vulnerable to climate change due to ice melt, temporal and spatial shifts in species interactions and distributions, and related processes (Pacifiçi et al., 2015).

Climate can affect carnivores also indirectly by influencing threats. The major threat to carnivores is their conflict with humans for space and food (Ripple et al., 2014). This conflict is particularly widespread with seven big cats, i.e.

tiger (*Panthera tigris*), lion (*Panthera leo*), jaguar (*Panthera onca*), leopard (*Panthera pardus*), snow leopard (*Panthera uncia*), cheetah (*Acinonyx jubatus*) and puma (*Puma concolor*), which kill domestic animals and sometimes even humans and thus inflict significant losses (Loveridge, Wang, Frank, & Seidensticker, 2010). Since most of these felids, except for puma, are globally threatened their retaliatory killing by people represents a major challenge for the synergy of rural development and biodiversity conservation, especially around protected areas (Inskip & Zimmermann, 2009). The impact of climate and its change on human-big cat conflicts is poorly understood and its limited conclusions are controversial. In some areas, cats kill livestock mostly during the wet season when wild prey disperses into reviving vegetation, regains fitness and thus becomes less available, whereas livestock enters these areas for uncontrolled grazing (Kolowski & Holekamp, 2006; Polisar et al., 2003). In other areas, the peak of livestock predation occurs in the dry season when limited cover decreases hunting success, wild prey moves away and livestock concentrates around a few water-holes (Dar, Minhas, Zaman, & Linkie, 2009; Schiess-Meier, Ramsauer, Gabanapelo, & König, 2007). This uncertainty can be aggravated by contradictory results from the same study areas (de Iongh & Bauer, 2008; van Bommel, Bij de Vaate, de Boer, & de Iongh, 2007).

As shown above, the effect of climate on conflicts has been considered through the mediating role of the availability of wild prey. However, other climate-driven factors such as diseases of predation-prone domestic animals may also contribute to conflicts. Diseases are widely known to be among the top problems for rural livelihoods (Dar et al., 2009; Kissui, 2008; Soto-Shoender & Giuliano, 2011), but the empirical research of their role in conflicts is still nascent (Khorozyan, Soofi, Hamidi, Ghoddousi, & Waltert, 2015).

In this paper, we address the relationships between climatic conditions and their change in the 21st century, diseases of domestic animals and human-leopard conflicts in Golestan National Park (Iran). This protected area accommodates the largest population of the globally endangered Persian leopard (*P.p. ciscaucasica* = *P.p. saxicolor*) which is under significant pressure of retaliatory killing by conflict-struck people



**Fig. 1.** Location of villages with and without the human-leopard (*Panthera pardus*) conflict around Golestan National Park (GNP) in north-eastern Iran.

(Hamidi et al., 2014). Albeit local in scope, this study raises important ecological questions of global relevance and practical value.

## Materials and methods

### Study area

Golestan National Park (GNP) was established in 1957 as a reserve, which was then upgraded to the first national park of Iran in 1967 and became a UNESCO Biosphere Reserve in 1976. Its current size is 874.02 km<sup>2</sup>. From west to east, elevations range from 450 m to 2411 m a.s.l. and the mean annual precipitation from 700 mm to 150 mm. The mean annual air temperature is 11.5–17.5 °C (Akhani, 2005). The main landscape zones are humid temperate Hyrcanian forest in the west, arid steppe in the central part and semi-desert in the east.

### Methods

We studied the relationships climate (bioclimatic variables) → diseases of domestic animals → human-leopard conflict in all 34 villages located in the Madarsou (Dough) River watershed around GNP (Fig. 1; Table 1). The numbers of livestock killed per year are random and their estimates are biased, viz. underestimated by low detectability of felid

scats and livestock carcasses or distorted from questionnaire surveys of local people (Dar et al., 2009; Kissui, 2008). To eliminate this bias, we defined conflict as a categorical variable (1, yes and 0, no) reflecting a situation in which at least one individual of cattle, sheep, goats and/or dogs was killed by leopards in a village during one year (March 2012 to March 2013). Diseases of domestic animals were taken as equivalent to dissatisfaction with veterinary services provided by vaccination crews (1, yes and 0, no). These crews are authorized to visit local villages once or twice a year for diagnostics, treatment and vaccination of domestic animals. In many villages, vaccination crews do not arrive at all or do it too late, leading to the spread of diseases in livestock and dogs and causing dissatisfaction among local people (Khorozyan et al., 2015). Probabilities of conflict and disease occurrence multiplied by 100% represented their presence, e.g. conflict probability of 0.3 meant 30% presence.

Structured questionnaire surveys were conducted in March and May 2013 among 41 council members of 34 villages, all of which are situated outside of GNP on unprotected lands. In our sample, they were 41.4 ± standard error (SE) 1.4 year-old men (range 25–74). These 41 persons represented the joint and agreed opinions of three council members (*Showra*) and one village head (*Deh-yar*) from each of 34 surveyed villages, so our survey practically covered 136 persons. Council members and village heads are the most respected, influential and knowledgeable persons elected by locals to represent their villages. Information provided by them was retrieved from the village databases (Khorozyan et al., 2015).

**Table 1.** Statistical information about 19 bioclimatic variables from 34 villages around Golestan National Park (Iran).

Variable	Description	Mean (standard error)	Range, min-max values
bio1	Annual mean temperature, °C	14.75 (0.20)	11.58–15.99
bio2	Mean diurnal range, mean of monthly air temperature $t_{\max} - t_{\min}$ , °C	12.73 (0.04)	12.46–13.38
bio3	Isothermality, $(\text{bio2}/\text{bio7}) \times 100\%$	36.13 (0.06)	35.38–36.64
bio4	Temperature seasonality, standard deviation SD $\times 100\%$	883.03 (3.56)	850.43–927.03
bio5	Maximum air temperature of warmest month, °C	33.46 (0.14)	31.00–34.40
bio6	Minimum air temperature of coldest month, °C	−1.77 (0.30)	−6.20–0.20
bio7	Annual range of air temperature, bio5–bio6, °C	35.24 (0.16)	34.00–37.60
bio8	Mean air temperature of wettest quarter, °C	9.36 (0.20)	7.42–12.48
bio9	Mean air temperature of driest quarter, °C	25.31 (0.21)	21.95–26.52
bio10	Mean air temperature of warmest quarter, °C	25.49 (0.16)	22.68–26.52
bio11	Mean air temperature of coldest quarter, °C	3.88 (0.25)	0.08–5.60
bio12	Annual precipitation, mm	259.88 (2.65)	219.00–282.00
bio13	Precipitation of wettest month, mm	46.65 (0.53)	40.00–51.00
bio14 <sup>a</sup>	Precipitation of driest month, mm	3.00 (0.00)	3.00–3.00
bio15	Precipitation seasonality, coefficient of variation (CV), %	71.57 (0.12)	70.37–73.82
bio16	Precipitation of wettest quarter, mm	123.12 (1.08)	110.00–133.00
bio17	Precipitation of driest quarter, mm	12.65 (0.09)	11.00–13.00
bio18	Precipitation of warmest quarter, mm	13.21 (0.16)	12.00–15.00
bio19	Precipitation of coldest quarter, mm	92.18 (1.65)	67.00–105.00

<sup>a</sup>This variable was not considered in data analysis because of its constancy across the villages.

Nineteen bioclimatic variables (bio1 to bio19) dated ~1950–2000 were retrieved and mapped in DIVA-GIS 7.5 with the 2.5 arc-min (~5 km) resolution maps of WorldClim – Global Climate Data ([www.diva-gis.org](http://www.diva-gis.org); Hijmans, Guarino, & Mathur, 2012) and overlaid with the GIS layers of villages and GNP boundaries (Table 1). The effect of climate change on diseases and conflict in GNP villages was analyzed in ArcGIS 10.1 (Esri Co., Redlands, USA) using the 2.5 arc-min Community Climate System Model (CCSM4) maps at representative conservation pathways rcp2.6 and rcp8.5 which provide the lowest and highest projections of air temperature changes, respectively ([www.worldclim.org](http://www.worldclim.org); IPCC, 2013). The assumption was that true climate change in GNP should lie in between the rcp2.6 and rcp8.5 scenarios. The CCSM model provides the most accurate information on climate change in the Middle East, including Iran (Evans, 2009). Village-specific climate change projections were retrieved for the periods of 2041–2060 and 2061–2080.

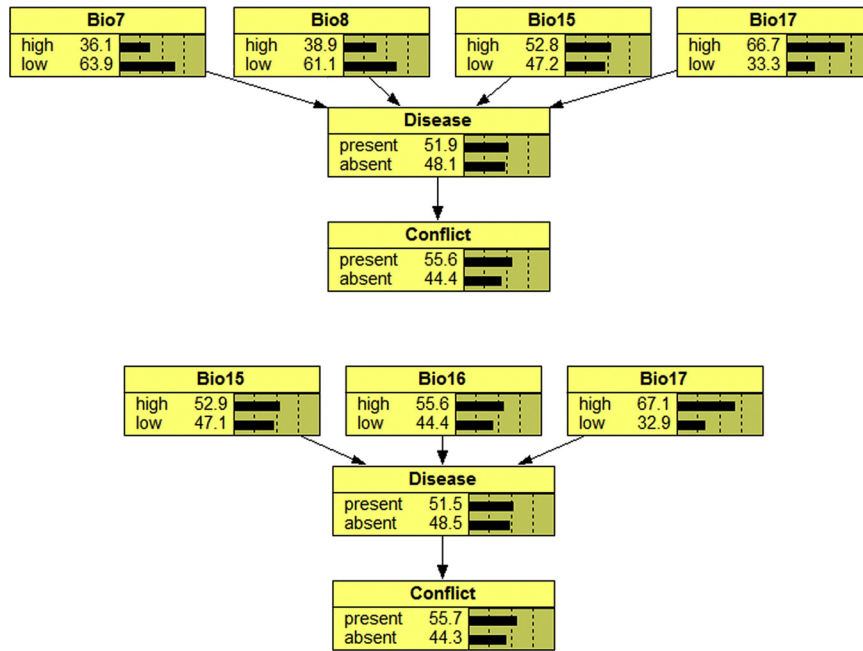
The Spearman rho ( $\rho$ ) correlation matrix was constructed for bioclimatic variables and different combinations of uncorrelated variables were tested as predictors for the response variable of diseases (see Appendix A). Multicollinearity was checked by variance inflation factor (VIF) and the predictors with  $VIF > 10$  were removed from further analysis as redundant (Quinn & Keough, 2002). The variable of bio14 was excluded as it was equal for all villages (Table 1).

Generalized linear regression (GLM), Multivariate Adaptive Regression Splines (MARS) and Bayesian Belief Network (BBN) were applied to build the climate–disease and disease–conflict models (Fig. 2; Table 2). The MARS models were built in Salford Predictive Modeler SPM v. 7.0 (Salford Systems, San Diego, CA, USA), automatically

optimized for their basic functions, tested for significance by ANOVA  $F$ -test and validated by generalized cross-validation (GCV) (Leathwick, Rowe, Richardson, Elith, & Hastie, 2005; Kanagaraj, Wiegand, Mohamed, & Kramer-Schadt, 2013). The key element of MARS models is the basic function which consists of a coefficient and a hinge function. A hinge function takes the form of  $\max(0, x-A)$ : it equals to  $x$  if  $x > A$ , otherwise it is zero. Alternatively, in  $\max(0, A-x)$  it equals to  $x$  if  $x < A$ , otherwise it is zero. The value of  $A$  is a constant called knot at which the MARS regression line changes its direction (Leathwick et al., 2005).

Additionally, the disease–conflict relationship was checked by  $2 \times 2$  contingency table chi-square ( $\chi^2$ ) test. The effect of climate on diseases was also estimated from bioclimatic variables (BIOCLIM model) and Gower distances of similarity (DOMAIN model) in grid cells with GNP villages in DIVA-GIS 7.5 (Kanagaraj et al., 2013; Fig. 3). The grid size was  $5 \times 5$  km corresponding to the resolution of WorldClim maps. This resolution is appropriate for the description of conflicts as livestock and dogs do not go far from their villages and thus are unlikely to be killed by leopards beyond the village grid. BBN was implemented in Netica v. 5.15 (Norsys Software Corp., Vancouver, Canada) (Bashari & Hemami, 2013). To fit the probabilistic pattern of BBN's, each bioclimatic variable was categorized as high (if  $|\text{value}| \geq |\text{mean}|$ ) or low (if  $|\text{value}| < |\text{mean}|$ ) for each village. The absolute value was taken to address the variables with negative values, like bio6 (minimum air temperature of coldest month, Table 1).

Statistically significant models were used to estimate the effect of climate change on diseases and the resulting effect of diseases on conflict. For this, we compared the values



**Fig. 2.** The Bayesian Belief Network of relationships between bioclimatic variables, diseases of domestic animals and the human-leopard conflict around GNP.

of response variables (diseases and conflict) calculated from current (~1950–2000) and projected (2041–2060 and 2061–2080) values of significant predictors (bioclimatic variables and diseases) (Table 3). The non-parametric Wilcoxon signed-rank test and Friedman test were used to compare the difference in estimated predictors and response variables across the model scenarios (rcp2.6 vs. 8.5) and projection years (2041–2060 vs. 2061–2080 vs. current time), respectively (Dytham, 2011).

The area under Receiver Operating Characteristic (AUC) was applied to validate the predictive power of the models (Table 2). A score AUC=0.5 means that the model has no discriminatory ability (in our case, disease vs. no-disease and conflict vs. no-conflict villages) and AUC=1 means that presences and absences are perfectly discriminated (Leathwick et al., 2005). The sample of 34 villages was split randomly into two sub-samples: 80% for training set and 20% for test set.

Statistical analysis was done in SPSS 17.0 (IBM, Armonk, NY, USA), unless otherwise indicated, using two-tailed significance level  $P$ . Standard error (SE) was used throughout the paper as a measure of estimate variation.

## Results

Out of 18 combinations of uncorrelated bioclimatic variables (see Appendix A), only two sets (first: bio7, bio8, bio15, bio17; second: bio15, bio16, bio17) produced significant effects on diseases and we proceeded with the analysis of these sets only. The variables bio15 and bio17 were included

in both these sets, but they alone were insufficient to affect diseases (logistic regression: omnibus  $\chi^2 = -0.280$ ,  $P = 0.597$ ; MARS:  $F = 0.361$ ,  $P = 0.701$ ). Multicollinearity in each set was absent as variable VIF ranged from 1.246 to 2.193 (see Appendix A).

## Climate and diseases

The logistic model M1 comprising bio7, bio8, bio15 and bio17 had much higher statistical significance, percentage of correct classification and predictive power than the logistic model M2 with bio15, bio16 and bio17 and the MARS model M4 with bio7, bio8, bio15 and bio17 (Table 2).

The BBN of climate–disease relationships showed that individual bioclimatic variables did not make a significant impact on diseases (Fig. 2). Setting variables at the maximum high or low levels (100% high, 0% low and 0% high, 100% low) caused variation in disease presence within 47.6–56.0% and in conflict presence within 53.8–57.9%. These ranges of variation did not differ from 51.5 to 51.9% for disease presence and from 55.6 to 55.7% for conflict presence (Fig. 2). Similarly, the BIOCLIM and DOMAIN models did not reveal the effect of individual bioclimatic variables on diseases as their predictive power was similar in models with bio7, bio8, bio15 and bio17 (BIOCLIM: AUC=0.857, DOMAIN: AUC=0.948), bio15, bio16 and bio17 (BIOCLIM: AUC=0.811, DOMAIN: AUC=0.938) and all 19 bioclimatic variables (BIOCLIM: AUC=0.868, DOMAIN: AUC=0.935). However, DOMAIN models had higher AUC values and therefore their predictive power was higher than

**Table 2.** The logistic regression and Multivariate Adaptive Regression Splines (MARS) models built to predict the probabilities of diseases of domestic animals and human-leopard conflict in villages around GNP.

a. Logistic regression						
Model	Description	Omnibus $\chi^2$	<i>P</i>	%	AUC	
Climate–disease model						
M1	$p(\text{diseases}) = 1/[1 + \exp(704.406 \times \text{bio7} + 620.279 \times \text{bio15} + 1393.763 \times \text{bio17} + 3.070 \times \text{bio7} \times \text{bio8} - 10.204 \times \text{bio7} \times \text{bio15} - 1.482 \times \text{bio8} \times \text{bio15} - 19.419 \times \text{bio15} \times \text{bio17} - 43,549.34)]$	18.683	0.009	84.8	0.886	
M2	$p(\text{diseases}) = 1/[1 + \exp(262.354 \times \text{bio17} - 27.758 \times \text{bio16} + 0.387 \times \text{bio15} \times \text{bio16} - 3.662 \times \text{bio15} \times \text{bio17} + 6.621)]$	9.576	0.048	75.8	0.801	
Disease–conflict model						
M3	$p(\text{conflict}) = 1/[1 + \exp(0.875 - 2.342 \times p(\text{diseases}))]$	9.435	0.002	75.8	0.761	
b. MARS						
Model	Description	<i>F</i> -test	<i>P</i>	%	GCV	AUC
Climate–disease model						
M4	$p(\text{diseases}) = 3.451 + 0.114 \times \max(0, \text{bio8} \times \text{bio15} - 683.24) - 0.165 \times \max(0, 683.24 - \text{bio8} \times \text{bio15}) + 0.056 \times \max(0, \text{bio8} \times \text{bio15} - 657.59) + 0.499 \times \max(0, \text{bio7} \times \text{bio15} - 2470.24) - 0.443 \times \max(0, 2470.24 - \text{bio7} \times \text{bio15}) - 34.007 \times \max(0, \text{bio7} - 35.1) + 30.007 \times \max(0, 35.1 - \text{bio7}) - 19.235 \times \max(0, \text{bio15} - 70.37) - 0.332 \times \max(0, \text{bio7} \times \text{bio8} - 331.58) + 0.361 \times \max(0, 331.58 - \text{bio7} \times \text{bio8})$	2.910	0.034	75.0	12.510	0.733
Disease–conflict model						
M5	$p(\text{conflict}) = 0.286 + 0.532 \times p(\text{diseases})$	8.939	0.007	77.8	0.500	0.750

Abbreviations:  $\chi^2$  – chi-square test statistic; *P* – significance level; % – percentage of correct classification; AUC – area under Receiver Operating Characteristic (ROC); GCV – MARS cross-validation statistic.

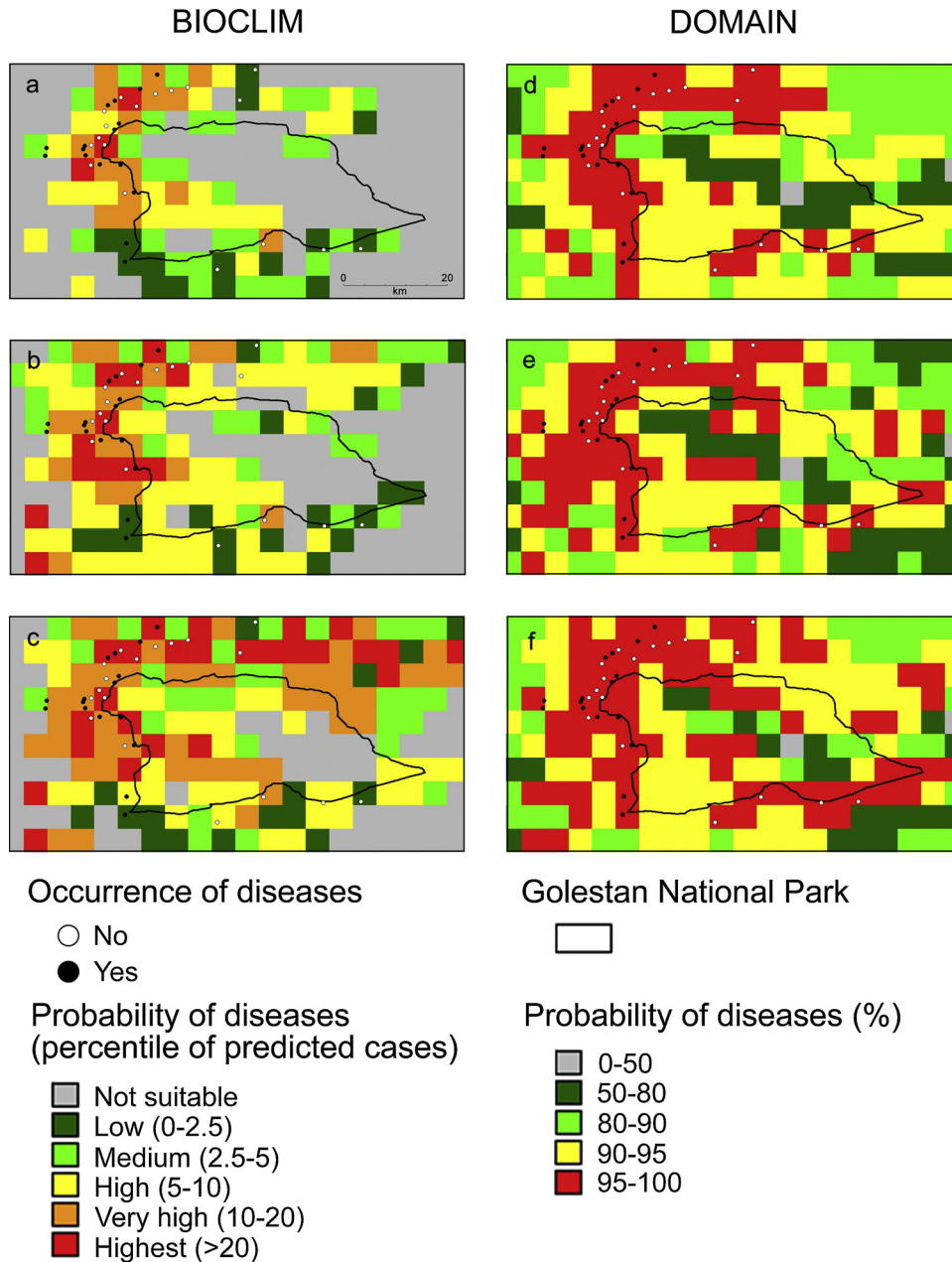
of BIOCLIM models. The maps of disease predictability by these two models are depicted in Fig. 3.

The climate change scenarios show that bio7 and bio8 will increase in 2041–2060 and 2061–2080 and that bio15 and bio17 will decrease in these projection periods in comparison with current estimates of these bioclimatic variables in GNP

villages (Table 3). This temporal trend was significant for all variables and scenarios (Friedman  $\chi^2$  varied from 32.882 to 68.000,  $P < 0.001$ ), except for bio17 under scenario rcp 2.6 ( $\chi^2 = 2.000$ ,  $P = 0.368$ ). The scenario rcp8.5 produced higher estimates of change than rcp2.6 (Table 3). This difference between the scenario estimates was significant for

**Table 3.** Projected changes of significant bioclimatic variables in 2041–2060 and 2061–2080 in 34 villages around GNP as estimated by the model CCSM4 scenarios rcp2.6 and rcp8.5. The values are indicated as arithmetic means, with a standard error in the parentheses. Full names of bioclimatic variables are provided in Table 1.

Bioclimatic variable	Current time	2041–2060		2061–2080	
		rcp2.6	rcp8.5	rcp2.6	rcp8.5
bio7, °C	35.24 (0.16)	+0.87 (0.04)	+1.25 (0.01)	+0.68 (0.03)	+2.41 (0.04)
bio8, °C	9.36 (0.20)	+1.39 (0.15)	+2.42 (0.38)	+1.96 (0.25)	+3.52 (0.63)
bio15, %	71.57 (0.12)	−5.84 (0.11)	−10.19 (0.11)	−7.43 (0.07)	−8.07 (0.10)
bio17, mm	12.65 (0.09)	−0.03 (0.03)	+0.15 (0.09)	−0.03 (0.03)	−0.62 (0.08)



**Fig. 3.** Probability of disease occurrence in domestic animals in GNP villages predicted by BIOCLIM (a – all 19 bioclimatic variables, b – variables bio7, bio8, bio15 and bio17, c – bio15, bio16 and bio17) and DOMAIN (d – 19 bioclimatic variables, e – bio7, bio8, bio15 and bio17, f – bio15, bio16 and bio17) models. Full names of bioclimatic variables are provided in Table 1.

each projection period (Wilcoxon signed-rank  $Z$  varied from  $-5.231$  to  $-2.113$ ,  $P$  from  $<0.001$  to  $0.035$ ), except for bio17 in 2041–2060 ( $Z = -1.897$ ,  $P = 0.058$ ).

Disease probabilities estimated by the logistic regression model M1 did not differ between the scenarios rcp2.6 and rcp8.5 (2041–2060: Wilcoxon  $Z = -0.577$ ,  $P = 0.564$ ; 2061–2080:  $Z = -0.447$ ,  $P = 0.655$ ). According to M1 predictions, disease probabilities in GNP villages will decrease by  $0.184 \pm 0.085$  or 18.4% in 2041–2060 (rcp8.5) and by  $0.214 \pm 0.076$  or 21.4% in 2041–2060 and 2061–2080 (rcp2.6 and rcp8.5). This change over years was

significant (rcp2.6: Friedman  $\chi^2 = 30.414$ ,  $P < 0.001$ ; rcp8.5:  $\chi^2 = 26.396$ ,  $P < 0.001$ ). The MARS model M4 (Table 2) performed poorly under climate change scenarios as its disease probabilities were beyond the range 0 to 1.

### Diseases and conflict

The logistic model M3 and the MARS model M5 had equally high fit and predictive power in estimating conflict probability from disease probability (Table 2). The  $2 \times 2$  table

$\chi^2$  test has shown that villages where diseases occurred had a significantly higher probability of human-leopard conflict (Pearson  $\chi^2 = 8.933$ ,  $P = 0.003$ ). In the BBN, setting disease presence at 100% increased conflict presence up to 77.8% with bio7, bio8, bio15 and bio17 and up to 79.4% with bio15, bio16 and bio17 (Fig. 2).

When using the logistic model M3 under climate change scenarios, conflict probabilities did not differ between rcp2.6 and rcp8.5 (2041–2060: Wilcoxon  $Z = -0.577$ ,  $P = 0.564$ ; 2061–2080:  $Z = -0.447$ ,  $P = 0.655$ ). In M3, conflict probabilities in GNP villages will decrease by  $0.104 \pm 0.045$  or 10.4% in 2041–2060 (rcp8.5) and by  $0.119 \pm 0.041$  or 11.9% in 2041–2060 and 2061–2080 (rcp2.6 and rcp8.5). This change over years was significant (rcp2.6: Friedman  $\chi^2 = 30.414$ ,  $P < 0.001$ ; rcp8.5:  $\chi^2 = 26.396$ ,  $P < 0.001$ ). Like in the case of the model M4, the MARS model M5 (Table 2) failed in climate change predictions by estimating conflict probabilities beyond 0 to 1.

## Discussion

We suggest that the annual range of air temperature, mean air temperature of the wettest quarter, precipitation seasonality and precipitation of the driest quarter make an interactive effect on the probability of disease occurrence in domestic animals of the study area (Table 2; Figs. 2 and 3). This relationship is best described by logistic regression (model M1 in Table 2) which also allows to reliably predict the probability of disease occurrence. Thus, the annual range of air temperature (climate continentality) and precipitation characteristics play the key role in the occurrence of diseases. In their turn, diseases increase livestock predation by leopards and thus stimulate human-leopard conflicts (Khorozyan et al., 2015). The descriptive and predictive logistic regression and MARS models demonstrate this link (Table 2). The most common disease in GNP villages is hoof infection caused by *Fusobacterium necrophorum*, which impedes free movement of livestock. It is widespread in Hyrcanian humid forest landscapes of western GNP, hinting at the dominant role of precipitation in disease spread (Fig. 1). Perhaps, hoof infection also limits the fleeing behavior of livestock and exposes them to higher predation (Khorozyan et al., 2015). Other diseases common in Golestan Province where GNP conflict and disease-affected villages are located include fascioliasis, foot-and-mouth disease, echinococcosis and tick-borne diseases (Hosseini, Meshgi, Abbassi, & Eslami, 2012; Jafarzadeh, Norris, & Thurmond, 2014; Mansoorlakoora et al., 2011; Sofizadeh, Telmadarrai, Rahnama, Gorganli-Davaji, & Hosseini-Chegeni, 2014). We are not aware of published research of livestock diseases in GNP villages and appeal for urgent implementation of predator-prey (livestock)-disease investigations here.

Of particular interest is to see the trend of climate change, viz. among the predictor bioclimatic variables, and to track its impact on disease and conflict probabilities in the study

area. Table 3 shows that climate continentality and mean air temperature of the wettest quarter will increase, whereas precipitation seasonality and precipitation of the driest quarter will decrease in the GNP area during the projection period 2041–2080. This is a clear sign of aridization which will be faced by this area in the 21st century. According to Amecy Juárez et al. (2013), GNP and adjacent lands is one of the world's mammal-rich areas most susceptible to droughts. Other studies also confirm that GNP will experience a decline of mean annual precipitation, air humidity and water flow balance, along with an increase of mean annual air temperature and a prolongation of the dry season in this century (Abbaspour, Faramarzi, Ghasemi, & Yang, 2009; Evans, 2009; Kousari, Ekhtesasi, Tazeh, Saremi Naeni, & Asadi Zarch, 2011). Interestingly, these authors show the opposite climate change trends in GNP (aridization) and in Golestan Province (increase of precipitation). The reason is that this province is situated mostly in the Hyrcanian humid temperate forest zone, whereas GNP lies in the transitional zone of Hyrcanian humid forests, steppes and semi-deserts and is more exposed to desertification coming from the east (Fig. 1; Akhani, 2005).

Aridization of GNP and its environs in 2041–2080 will lead to the reduction of disease probability by 18.4–21.4% and conflict probability by 10.4–11.9% in the same period. Currently, human-leopard conflicts occur only in humid forest areas of western GNP (Fig. 1). Several wild prey species exist inside GNP at quite high densities: wild boar (*Sus scrofa*) throughout the park, wild sheep or urial (*Ovis vignei*) in steppes and goitered gazelle (*Gazella subgutturosa*) in semi-desert. The bezoar goat (*Capra aegagrus*) is uncommon in rocky areas and red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) are rare in forests (Hamidi et al., 2014; Ghoddousi et al. and Soofi et al., unpublished results). We expect that high-density ungulates, which are all tolerant to dry conditions, may further ameliorate human-leopard conflict in GNP under progressing aridization. It is unclear how livestock numbers will change under aridization in GNP, while the leopard population is known to decrease because of poaching and road kills (Hamidi et al., 2014). However, we recently showed that leopard and other felid attacks on livestock are inversely related to biomass and, to a lesser extent, to density of wild prey irrespective of livestock and felid densities (Khorozyan et al., unpublished results). It means that leopard attacks would not be affected by human and, hence, livestock densities or leopard numbers, unless wild prey resources go down. Therefore, more research is needed to elucidate the role of wild prey in the relationships between climate and its change, livestock predation and human-carnivore conflicts and to enforce conservation commitment to recover wild prey resources, especially ungulates. Particularly in GNP villages, it is imperative to conduct socially oriented projects to reduce poaching and to increase public acceptance of leopards, which have a phenomenal ability to survive even in anthropogenic landscapes by killing domestic animals alone (Athreya, Odden, Linnell, Krishnaswamy, & Karanth



2014; Shehzad et al. 2014). This is in line with other research which explicitly shows that human density is a poor predictor of carnivore loss while other factors such as legislation, attitudes and policymaking are more important to secure the well-being of carnivores (Linnell, Swenson, & Andersen, 2001).

This study confirms that conflicts between humans and big cats are most common in humid conditions when dispersed and scattered wild prey is replaced by livestock entering lush vegetation for grazing (de Iongh & Bauer, 2008; Kissui, 2008; Kolowski & Holekamp, 2006; Polisar et al., 2003; Soto-Shoender & Giuliano, 2011). Notably, large-bodied big cats heavily depend on wild ungulates and thus tend to be more climate-dependent in livestock-taking than their smaller cousins (lion vs. leopard – Schiess-Meier et al., 2007; Kissui, 2008; jaguar vs. puma – Rosas-Rosas, Bender, & Valdez, 2008). Lack of difference between larger and smaller big cats may occur in cases when certain seasons favor the appearance of juvenile livestock (calves, lambs, kids) optimal for both classes of big cats (Polisar et al., 2003; Soto-Shoender & Giuliano, 2011). The leopard is the only big cat surviving today in the Middle East and its individuals living in GNP are among the largest (Khorozyan, 2014), so their reliance on humid conditions for livestock predation is plausible.

## Conclusions

Little is known about the effects of climate and its change on conflicts between humans and carnivores over their predation on domestic animals. Our study is the first empirical effort concluding that climate continentality and precipitation patterns affect the occurrence of diseases in domestic animals and that more diseases lead to more human-leopard conflicts in a humid environment. Aridization projected for the 21st century will decrease disease and conflict probabilities. More research is needed to address the climate–disease–conflict relationships and the role of wild prey in them.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.baae.2015.07.001>.

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