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Leveraging trans-boundary conservation partnerships: Persistence of Persian leopard (*Panthera pardus saxicolor*) in the Iranian Caucasus

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ABSTRACT

Ranging across montane areas of west Asia, the endangered Persian leopard *Panthera pardus saxicolor* is a flagship species for biodiversity conservation in the Caucasus Eco-region. Despite recent reduction in occupancy and number within the range countries, the subspecies still exists in large areas within Iran, including the northwest which is considered the only promising source from which this leopard might recolonize its former range. In this context, we sought to elucidate the species' status and habitat requirements, and to evaluate the effectiveness of protected areas in safeguarding its long-term persistence. We report 150 locations where the Persian leopard was recorded across six provinces in the Iranian Caucasus Eco-region. These records informed a consensus species distribution modeling approach using 14 uncorrelated environmental variables (landcover, topographic, anthropogenic and climatic features) to explore the distribution of habitats suitable for the leopards. Using electrical-circuit theory we then explored connectivity between the usable habitats as revealed by this model. Unsurprisingly, our models confirmed that prey availability and the avoidance of humans were the primary influences on leopard distribution in the region. Two main landscapes were revealed to be suitable for the leopard but only 30% of their 20,026.9 km^2 area is officially protected. The Alborz landscape hosted the larger population nucleus and majority of breeding occurrences. Modeled connectivity revealed that persistence of the Persian leopard population in the boundary landscape and the broader Lesser Caucasus Mountains is dependent on trans-boundary movements through southern Azerbaijan. We conclude that it is a priority that international collaboration secures the Persian leopard's conservation in the wider landscape spanning the borders of Caucasian countries.

1. Introduction

As the only extant big cat within Eurasia, the Persian or Caucasian leopard *Panthera pardus saxicolor*, is a flagship species distributed in the remote mountains and rugged foothills of Iran, Afghanistan, Turkmenistan, Azerbaijan, Iraq and the broader Caucasus (Breitenmoser et al., 2007; Gavashelishvili and Lukarevskiy, 2008). Despite its importance, this endangered subspecies has remained in a precarious situation, at low density and within a shrinking range since the mid-20th century (Heptner and Sludskij, 1972; Bragin, 1990; Khorozyan, 2003; Başkaya and Bilgili, 2004; Breitenmoser et al., 2007, 2010; Gavashelishvili and Lukarevskiy, 2008).

Ranked among the planet's 34 most diverse and endangered hotspots (Mittermeier et al., 2004), the Caucasus Eco-region covers a total area of 580,000 km^2, extending over the entirety of Armenia, Azerbaijan and Georgia, part of the Russian Federation, north-eastern Turkey, and part of north-western Iran (Williams et al., 2006; Zazanashvili et al., 2007). The leopard has been nominated as a focal priority species for conservation in the Eco-region (Williams et al., 2006; Zazanashvili et al., 2007), within which its population comprises no more than 65 individuals (Lukarevsky et al., 2007); this number might realistically, although ambitiously, be increased to 600–1200 if conservation efforts are properly targeted within the potential Caucasus meta-population (Zimmermann et al., 2007). It seems that only very small numbers of Persian leopards persist in range-countries beyond Iran (Lukarevsky et al., 2007; Khorozyan et al., 2008; CLWG, 2014; Askerov et al., 2015) — these areas probably function as peripheral sinks for the larger Iranian pool (Breitenmoser et al., 2010). In contrast, this subspecies is thought to be more abundant in the northwest of Iran, in the part of the country comprising the Caucasus Eco-region (Kiabi et al., 2002; Lukarevsky et al., 2004) and these animals may be the only likely source stock for natural re-colonization of the Caucasus

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population (Khorozyan and Abramov, 2007; Lukarevsky et al., 2007; Breitenmoser et al., 2010).

Against this background, the reality is that little is known of the Persian leopards and their status in northwestern Iran, nor of the threats they face (Breitenmoser et al., 2010). Worse, a recent investigation by Moqanaki et al. (2013) within what had previously been considered as promising reserves in northwestern Iran revealed that the leopards there were in unfavorable status. It is believed that connectivity with the nucleus of Iran's Persian leopard population, mainly through the Alborz, is essential for the sub-species' viability across the region (Zimmermann et al., 2007; Gavashelishvili and Lukarevskiy, 2008).

Species distribution models (SDMs; Guisan and Zimmermann, 2000) have been widely used to identify suitable habitat for rare species (Franklin, 2010), evaluating species distribution over large and remote landscapes (Brito et al., 2009), estimation of population size over large areas (Hebblewhite et al., 2011), prioritizing areas for conservation (Carvalho et al., 2011), and assessment of potential effects of global change in species distribution (Thuiller et al., 2006; Maiorano et al., 2011). Furthermore, regarding landscape attributes, SDMs and the concept of habitat connectivity are useful tools for the study of broad-scale ecological processes including species dispersal, gene flow, metapopulation dynamics and maintenance of biodiversity (McRae and Beier, 2007; Rabinowitz and Zeller, 2010). Previous studies have attempted to assess the range of the Persian leopard in west and central Asia using different statistical models (Gavashelishvili and Lukarevskiy, 2008), and in the Caucasus Eco-region (Zimmermann et al., 2007). They were, however, hampered by a lack of representative data from the entire range of the Persian leopards in northwestern Iran and, anyway, it is useful continuously to up-date such assessments (Moqanaki et al., 2013).

In general, leopards in western Asia occur in rugged terrain with little human disturbance (Zimmermann et al., 2007; Gavashelishvili and Lukarevskiy, 2008; Omidi et al., 2010; Erfanian et al., 2013). However, the species can adapt to living alongside dense human populations in completely modified landscapes (Athreya et al., 2013). While prey density is the key predictor of leopard occurrence (Omidi et al., 2010; Hebblewhite et al., 2011; Erfanian et al., 2013), high prey densities are shown to be associated with surprisingly low densities of leopards in the Caucasus, perhaps due to poaching and disturbance (Khorozyan et al., 2008) or inadequate dispersal from source areas (Lukarevsky et al., 2007). Furthermore, climatic covariates, such as snow depth, may affect habitat suitability for the leopard in these landscapes (Gavashelishvili and Lukarevskiy, 2008; Hebblewhite et al., 2011), although not at a fine scale (Omidi et al., 2010; Erfanian et al., 2013).

Against this background, we undertook a landscape-scale analysis of leopard distribution and habitat quality with the following objectives: 1) to model, and predict, the distribution of Persian leopards in NW Iran, 2) to identify, habitat suitable for the subspecies' long-term survival, 3) to assess landscape connectivity among important habitat patches, and 4) to evaluate the efficacy of the existing conservation areas (hereafter CAs) in safeguarding the leopard in the region. Our results provide a foundation on which to base a conservation strategy for the Persian leopard in the Iranian Caucasus Eco-region.

2. Methods

2.1. Study area

The present investigation was carried out in northwestern Iranian uplands (35° 24' to 39° 48' N and 44° 02' to 50° 48' E), covering the Lesser Caucasus and western Alborz Mountain chains. It consisted of two major regions, Arasbaran and Hyrcan, which constitute the southern stretches of the Caucasus (Transcaucasia) (Asef and Muradov, 2012). Conventionally, only the northern parts of Ardebil, West and East Azerbaijan and the province of Gilan are included in the Caucasus Ecoregion (Williams et al., 2006). Only the northern slopes of the Alborz mountains, which are one of the strongholds of leopards in Iran (Kiabi et al., 2002; Lukarevsky et al., 2007) lie within Gilan province and are thus encompassed in the Eco-region, which thereby excludes those leopards occupying the southern face of the Alborz. To remedy this we incorporated into our analysis two southern provinces, Qazvin and Zanjan, which together cover the southern face of Alborz, such that our total study area measured 152,243 km^2.

Located in the Anatolian region (Zehzad et al., 2002), the Caucasian part of Iran exhibits two distinct plant communities. Hyrcanian forests range from Talysh in the Republic of Azerbaijan along northern face of the Alborz Mountains, typified by tree species such as *Parrotia persica*, *Gleditsia caspica*, *Zelkova carpinifolia* and *Pterocarya fraxinifolia* (Akhani et al., 2010). In contrast, the rest of the landscape is characterized by treeless rocky ravines and steppe highlands and hills.

Some steep slopes are covered with sparse forests (Lukarevsky et al., 2007). The northwest Iranian mountains form more or less distinct highlands in the inner part of Iran including several well-known peaks (e.g. Mt. Sabalan, 4811 m.a.s.l.; Mt. Sahand, 3707 m.a.s.l.).

The mean annual precipitation ranges between 800 to 2000 mm in the Caspian lowlands and between 250 and 800 mm in the highlands which are located in western part of this region. The saline Urumia Lake basin covers 4868 km^2 (Zehzad et al., 2002). There are over 120 towns/cities and 140 villages with a total population of more than 9 million people in the Caucasian part of Iran and two southern provinces (Statistical Center of Iran, 2011).

The Persian leopard shares these areas with a wide range of mammalian species, including Syrian brown bear *Ursus arctos syriacus*, gray wolf *Canis lupus*, Eurasian lynx *Lynx lynx*, wild cat *Felis sylvestris*, Maral red deer *Cervus elaphus maral*, roe deer *Capreolus capreolus*, wild boar *Sus scrofa*, wild goat *Capra aegagrus* and Armenian mouflon *Ovis orientalis* (Ziaie, 2008).

2.2. Data collection

We collated a database composed of 242 leopard point localities recorded from 2000 to 2014, compiled from existing literature on Persian leopard from Iran and border areas, leopard records gathered by Iranian Department of the Environment (DoE) and information resulting from interviews with wildlife experts, game wardens, hunters and taxidermists with the exact name and geographical position of the locations. In addition, we personally visited some areas to find reliable evidence of the leopard, including scrapes and tracks. We were not able to validate 92 records, which were excluded from our dataset. In order to reduce spatial autocorrelation, we excluded all multiple occurrences of sites within a minimum distance of 2.5 km (corresponding to the mean maximum distance moved (MMDM) by Persian leopards, i.e. 5 km; Ghoddousi et al., 2010). For most of the records precise geographic coordinates were available, for the remainder a general description of the locality or local name of the sites were available, therefore, we used Google Earth 5.0.1 to extract the coordinates.

2.3. Habitat variables

Four sets of ecogeographical variables (hereafter EGV) were selected for Persian leopard distribution models according to their acknowledged relevance to the ecology and distribution of the species (Gavashelishvili and Lukarevskiy, 2008; Balme et al., 2010; Swanepoel et al., 2013; Abade et al., 2014) including landcover, bioclimatic, topographic and anthropogenic variables. For landcover data we used cover types from Globcover v. 2.1 map (IONIA, 2009) at a 300 m resolution global dataset, which contains 63 cover types (including 15 types for our study area). We extracted cover types that described the natural background of the landscape (Table 1) and using neighborhood analysis, calculated the proportion of each cover type within 2.5 km radius (based upon the Persian leopard MMDM) centered in each cell. We also considered the normalized difference vegetation index (NDVI) as

Table 1
Ecogeographic variables (EGV) used for model the distribution of Persian leopard in the Iranian Caucasus Eco-region.

Variable	Abbreviation	Description	Source
Landcover	Forest	Proportion of forest cover	IONIA (2009)
	Shrub/forest	Proportion of the mosaic of shrubland–forest	
	Shrub	Proportion of shrubland	
	Grass/shrub	Proportion of the mosaic of grassland–shrubland	
	Grass	Proportion of closed to open herbaceous vegetation	
	Grass/crop	Proportion of the mosaic of grassland–cropland	
	Crop	Proportion of cropland	
	NDVI	Normalized difference vegetation index	MODIS (2010)
Climate	Anulmeantmp	Annual mean temperature	WorldClim (2005)
	Tmpsea	Temperature seasonality (standard deviation $*$ 100)	
	Anulprc	Annual precipitation	
	Prcseas	Precipitation seasonality (standard deviation/mean)	
Topography	Roughness	SD of altitude of all raster cells within a 2.5 km radius	SRTM
Anthropogenic	Human footprint	Index of population density, land transformation, human access, and presence of infrastructures	Sanderson et al. (2002)

a measure of primary productivity and a direct proxy for resource availability with its proven capability to reflect large herbivore ecology and distribution (Mueller et al., 2008; Pettorelli et al., 2011). The composite Moderate Resolution Imaging Spectrometer (MODIS), NDVI (MOD13Q1, available on: https://lpdaac.usgs.gov) was used to calculate the mean NDVI values for the year 2010. Bioclimatic variables which were incorporated in various habitat suitability models for other carnivores (e.g. Brito et al., 2009; Wilting et al., 2010; Marino et al., 2011) were obtained from WorldClim dataset (Hijmans et al., 2005). Because of the inherent high correlation between climatic variables, we limited them to those describing absolute values of temperature and humidity (e.g. annual mean temperature and annul precipitation) and variation in these climatic parameters through the year (e.g. temperature seasonality and precipitation seasonality). To provide congruence between the scales at which we measured landcover and climatic variables, we resampled landcover variables to the pixel size of climatic grids (1×1 km).

Using the Shuttle Radar Topography Mission (SRTM) elevation model (http://srtm.csi.cgiar.org), the two most important factors describing topographic context were compiled: elevation and standard deviation (SD) of the elevation of all raster cells included in aforementioned 2.5 km radius as a measure of physiographic roughness. To quantify anthropogenic impact we used human footprint as a measure of human influence on the land surface, calculated based on nine geographical datasets including vector maps, satellite images, and census data. By combining data of population density, land transformation, human access, and presence of infrastructures in this dataset (Sanderson et al., 2002), we assessed all effects of human activities in our distribution models.

Finally co-linearity between EGVs was limited to <0.7 using Pearson correlation coefficients. Consequently, elevation was dropped for modeling due to a high correlation with annual mean temperature. As a result, 14 landcover, climatic, topographic, and anthropogenic variables were produced as predictor variables at 1-km resolution (Table 1). All EGVs were prepared using ArcGIS 9.3 (ESRI, 2010).

2.4. Model construction

In order to develop a robust distribution model for Persian leopard we employed two concepts of simplicity and complexity. Simple models (e.g. global or statistical models) allowed us to extrapolate from the output of the distribution model in order to identify areas beyond the field surveys to identify areas suitable for the leopards (Merow et al., 2014). In parallel, using complex, machine learning methods, we sought a more accurate understanding of the determinants of the current distribution. Accordingly, we used two statistically-based models, first a generalized linear model (GLM; McCullagh and Nelder, 1989) and second a generalized additive model (GAM; Hastie and Tibshirani, 1990), as well as three machine learning algorithms including boosted regression trees (BRT; Elith et al., 2008), random forest (RF; Breiman, 2001) and maximum entropy (MaxEnt; Phillips et al., 2006) to develop Persian leopard distribution model in the region. We implemented BIOMOD framework using 'biomod2' package in R environment v 3.1.2 (R Development Core Team, 2014) to fit all models in the same controlling environment and also to combine them in an ensemble forecasting framework (Thuiller et al., 2009).

Since all these models require data on locations from which the subject is absent, we generated a random sample of 5000 background points from the environmental data. As no independent data existed to evaluate the predictive performance of the models and to deal with probable over-fitting, especially caused by complexity-based models (e.g. BRT, RF and MaxEnt; Franklin, 2010), a cross-validation procedure was implemented by randomly splitting occurrence points into a 10-fold data set. Modeling was repeated following the elimination of each fold in turn, and eliminated folds were used to create a data set for validation of the derived models. We used area under the receiver operating characteristic curve (AUC; ranging from 0.5 = random to 1 = perfect discrimination) as a threshold-independent criterion where values between 0.7–0.9 were considered as useful, and values > 0.9 as excellent (Fielding and Bell, 1997). For classification accuracy, as threshold-dependent criteria, we considered true skill statistic (TSS) and Cohen's Kappa calculated for all models. For each model evaluation criteria were averaged among validation subsets of 10 replicates. Importance, and thus the contribution of EGVs to each model was examined regarding Pearson rank correlation between standard predictions and those based on 5-times random permutation for each variable separately (Thuiller et al., 2009). For each EGV we averaged variable importance across all implemented models. Finally we combined concepts of both simple and complex modeling approaches into an ensemble model to deal with specific uncertainties of the SDMs and to maximize our understanding of the species distribution (Araújo and New, 2007; Thuiller et al., 2009; Merow et al., 2014). We implemented the ensemble model by weighted-averaging the individual models proportionally to all their evaluation metrics scores (Thuiller et al., 2009).

We also depicted response curves of EGVs to illustrate effects of the most important variables on the distribution of the Persian leopard. We fitted two independent models based on BRT and RF for all presence points to shape response curve of important EGVs and depict complex representativeness of Persian leopard occurrence–environment relationships. BRT and RF were fitted using the 'gbm' (Ridgeway, 2006) and 'randomForest' packages (Liaw and Wiener, 2002) respectively.

2.5. Coverage with conservation networks

In order to evaluate degree of protection granted to the Persian leopard by the designated conservation areas (CA) and to facilitate the planning of future CAs, we overlaid the ensemble suitability map with the polygon of Iran's conservation networks. We considered the minimum

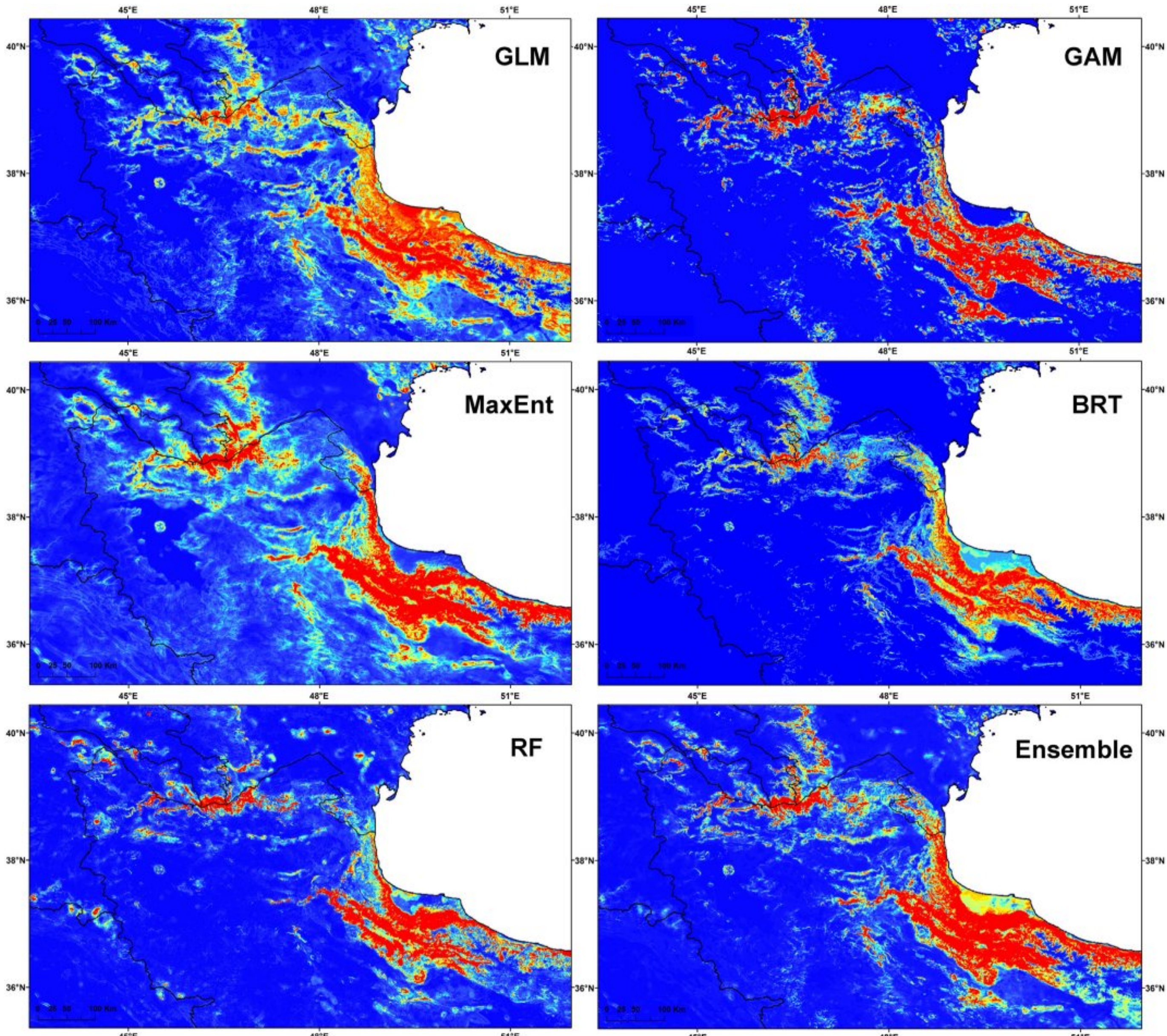

Fig. 1. Predicted distribution of Persian leopard in lesser Caucasus Eco-region based on five different distribution models and a consensus prediction of all models. GLM: generalized linear model, GAM: generalized additive model, MaxEnt: maximum entropy, BRT: boosted regression trees, RF: random forest, Ensemble: consensus prediction across all models.

ensemble score calculated for leopard presence points as a suitability threshold above which raster cells were classified as suitable areas. Since our goal is to foster the protection of Persian leopards we adopted a presence/absence threshold intended to ensure that the loss of areas predicted by our SDMs to be suitable for leopards was decreased. We therefore assumed that our threshold selection method, which resulted in a lower threshold value (and thereby a wider distribution of suitable habitats for the species), provides cautious goals for Persian leopard conservation.

2.6. Evaluating habitat connectivity

We combined our SDM with electrical-circuit theory to explore potential connectivity for movement of leopards using Circuitscape software v. 3.5 (McRae and Shah, 2009). Accordingly, the final ensemble model was used as an index of conductance (e.g. permeability of each raster point for movement); all cells connected by dispersal were replaced by electronic nodes connected by resistors (McRae et al., 2008) and current flow through whole landscape was estimated. The resulted map indicated current flow (analogous to probability of movement) between habitat patches through which dispersers move (McRae et al., 2008; Dickson et al., 2013). To identify important areas for

Table 2
Evaluation of five modeling algorithm predicting the distribution of Persian leopard in the Iranian Caucasus Eco-region. True skill statistic (TSS), area under the ROC curve (AUC) and Kappa were measured based on averaging validation subsets of a 10 fold data splitting on leopard occurrences.

	AUC	TSS	Kappa
GLM	0.850	0.637	0.382
GAM	0.910	0.723	0.415
MaxEnt	0.906	0.732	0.482
BRT	0.925	0.776	0.515
RF	0.910	0.710	0.520

Table 3
Mean independent variable importance and SD among the five models derived from BIOMOD. Variables importance was calculated based on the Pearson rank correlation between predictions of standard models and those of 5-times random permutation for each variable.

Variable	Mean importance	SD
Roughness	0.439	0.148
Tmpsea	0.316	0.196
NDVI	0.276	0.175
Anulmeantmp	0.212	0.146
Footprint	0.173	0.144
Shrub/forest	0.145	0.095
Anulprc	0.12	0.079
Forest	0.076	0.068
Grass/shrub	0.058	0.041
Prcseas	0.048	0.056
Grass	0.045	0.048
Grass/crop	0.042	0.040
Shrub	0.039	0.029
Crop	0.03	0.037

maintaining connectivity, we estimated current flow among identified breeding patches for Persian leopard (for more details see McRae et al., 2008).

3. Results

After excluding all multiple occurrences within a minimum distance of 2.5 km, 150 unique records of Persian leopard presence remained, and these were used to develop the Persian leopard distribution models. The distribution maps produced by each of the different models were almost indistinguishable (Fig. 1). Similarly, the models were consistent in their predictions of the whereabouts of low quality habitat for leopards. However, models based on decision trees (e.g. BRT and RF) were the most conservative in their assessment of areas with higher probability of presence (Fig. 1).

The performances of all models was excellent with regard to discrimination capacity (all AUC > 0.9, except for GLM with AUC = 0.850; Table 2), but BRT performed best. TSS scores of 0.64–0.78 indicated that the accuracy of all models was good, according to Allouche et al. (2006). Cohan's Kappa statistic was higher than 0.5 only for models based on decision tree algorithm (Landis and Koch, 1977).

Based on the mean value of variable importance given by BIOMOD, the top six EGVs affecting the distribution of Persian leopards in the Caucasus region of Iran were: roughness (SD of altitude; representing the diversity of relief shapes), temperature seasonality, NDVI, annual

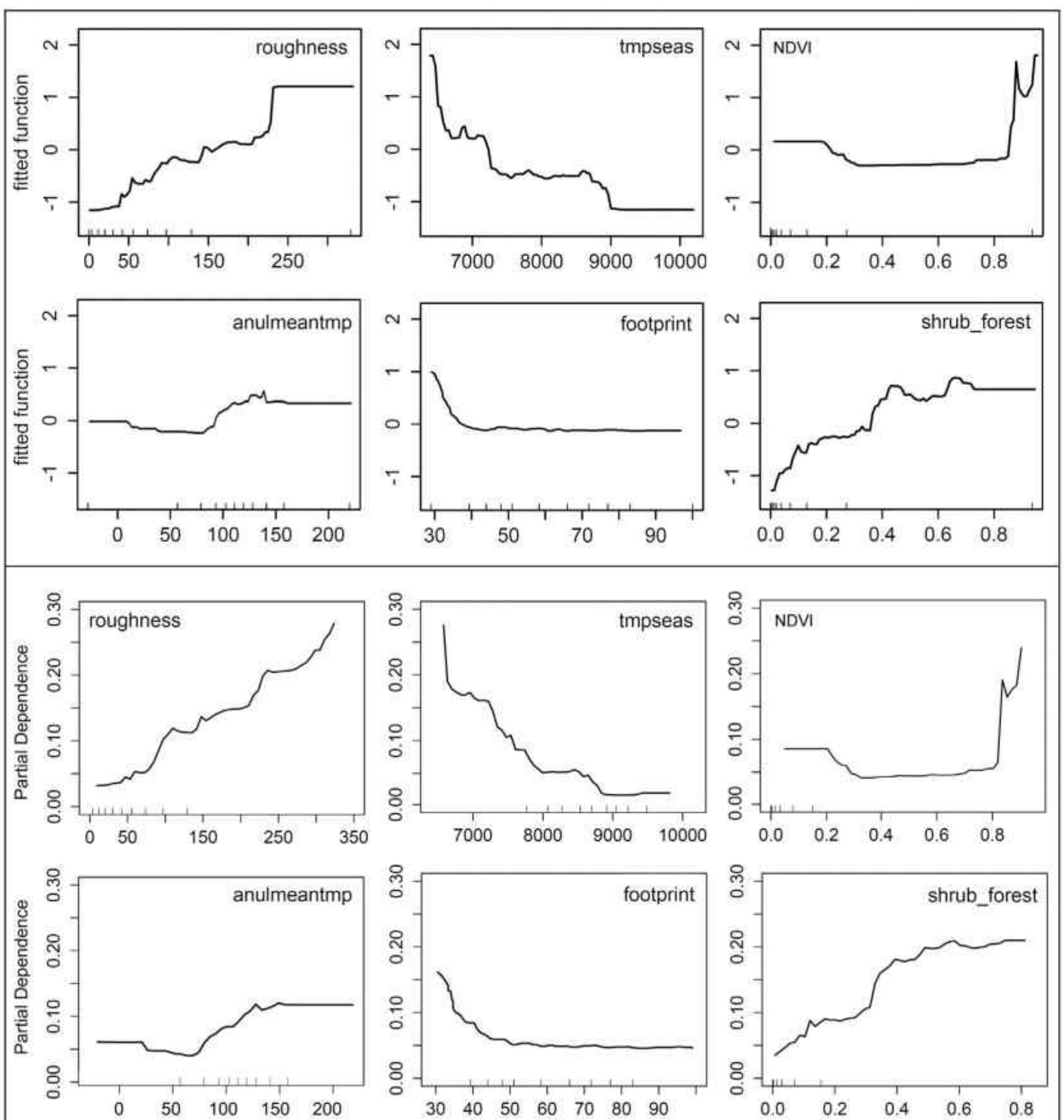

Fig. 2. Response curves of the most important variables affecting distribution of Persian leopard produced by BRT (up) and RF (down) models. For variables descriptions see Table 1.

mean temperature, human footprint and proportion of the mosaic of shrubland–forest (Table 3). The response curves produced for the six most important EGVs were almost indistinguishable for both BRT and RF (Fig. 2). These response curves indicated that the likelihood of the leopards occurring increased with increasing topographic roughness as well as NDVI and frequency of habitat patches covered by the mixture of shrubland–forest, and decreased with increasing human influences on the land (Fig. 2). Regarding climatic parameters, leopards were most likely to occur in areas with low variation in temperature across the year, where annual mean temperature ranges between 10–15 °C provided highest probability of the distribution for Persian leopard (Fig. 2).

The distribution probability scores calculated for the ensemble model ranged from 33 to 980. We set the minimum threshold for suitability of habitat for Persian leopards at a probability of occurrence equal to 450. On this basis, a total area of 23,809.01 km^2 was identified as suitable landscape for the leopard, representing 16.3% of the study area. In order to identify patches capable of sustaining breeding populations of leopards we excluded patches smaller than 250 km^2, on the basis that fieldwork has revealed areas larger than this to hold breeding populations of leopards in Iran (Farhadinia et al., 2009; Ghoddousi et al., 2010). As a result, three patches with a total area of 20,026.9 km^2 were diagnosed as suitable for breeding populations of Persian leopards (Fig. 3 and Table 4).

The data recorded leopards breeding in six localities, all lying within existing CAs (Fig. 3). Nearly 30% of suitable breeding habitats are already officially protected by the Iranian Department of Environment (Table 4). 10% of the suitable range lies at borderland with Armenia, Azerbaijan and Turkey (hereafter boundary landscape), the remainder lying within the interior of Iran (hereafter Alborz landscape). Superimposing the raw data on records of occurrence on the habitat suitability map produced by the models (see Fig. 3), suggests that all suitable patches are probably already occupied by the leopards.

Our map of cumulative current flow (Fig. 4) highlighted strong habitat connectivity within those parts of the leopard's range that lie at international borders, with important corridor areas spanning Iran and Azerbaijan. Furthermore, we could detect no existing connectivity between two important patches occupied by leopards in Iran, and the only plausible linkage between these nuclei and the rest of the Lesser Caucasus region was through southern Azerbaijan. However, this vital corridor was threatened by poor habitat quality and high concentration of human activities which result in weak conductance within the circuit model (Fig. 4).

4. Discussion

4.1. Habitat characteristics

We conclude that prey availability and human disturbance are the key determinants underlying the spatial configuration of leopards in this region. This conclusion is based on the large contribution to species distribution models of surface ruggedness, human footprint and NDVI, the latter we interpret as an index of prey abundance, water and vegetation productivity (Pettorelli et al., 2011). Furthermore, the leopards' selection of areas with lower temperature seasonality indicates that extreme temperatures are a constraint on their biogeography.

Our model also showed that mosaic patches of shrub and forests contribute to the Persian leopard's distribution, likely through maintaining forest-dwelling ungulates, such as Maral red deer, roe deer and wild boar, of which the latter still occurs at comparatively high density in Iran (Ziaie, 2008). Our model was based on only topographic, bioclimatic and anthropogenic data. However, prey is an essential predictor for leopard habitat suitability (Hebblewhite et al., 2011), so doubtless our model would be improved if data on prey availability were available.

Records of leopard occurrence indicated that breeding populations exist in both main landscapes, and are already substantially encompassed within the existing network of CAs. In contrast, no evidence of leopard reproduction has been reported from beyond Iran within the broader Caucasus since the late 1990s (Lukarevsky et al.,

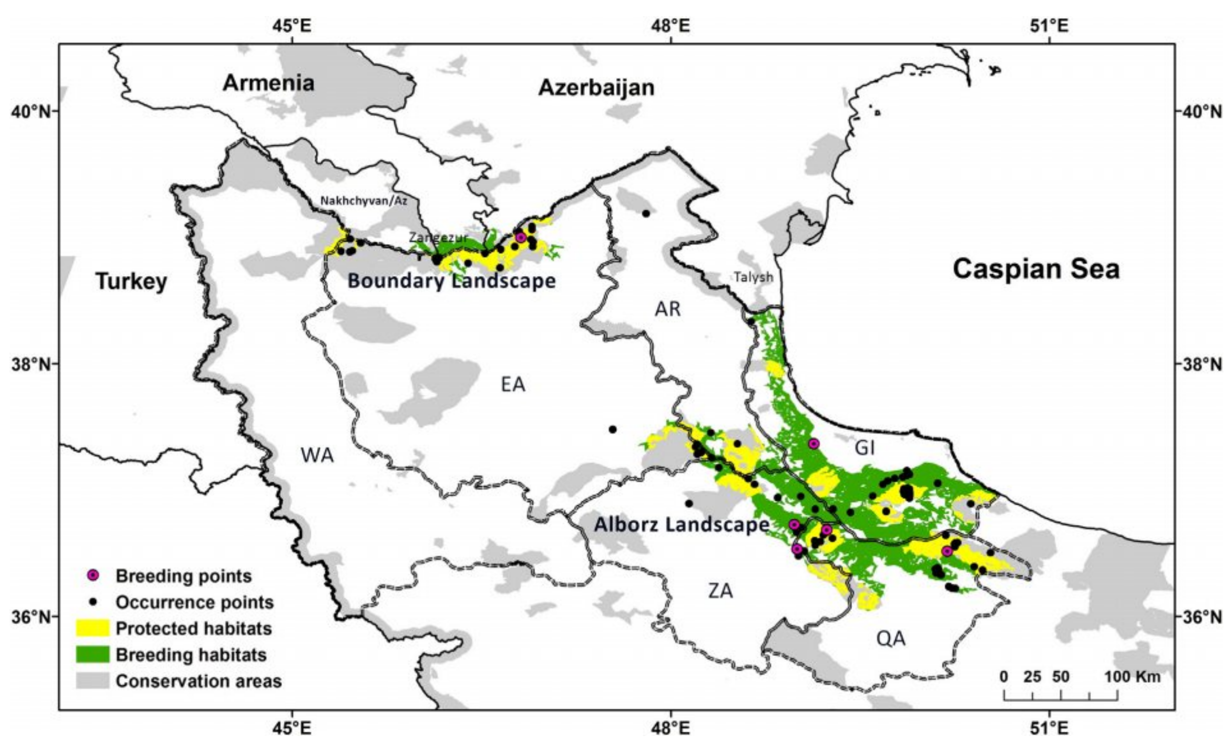

Fig. 3. An overlay of Lesser Caucasus' Conservation Network (composed of Iran, Armenia, Azerbaijan and Turkey) with the suitable habitats for Persian leopard. Dashed line represents six provinces in northwestern Iran (see Study area for more details). Abbreviations on the map denotes to provinces in Iran: GI: Gilan, QA: Qazvin, ZA: Zanjan, AR: Ardabil, EA: East Azerbaijan, WA: West Azerbaijan.

Table 4
Area and proportion of protection granted to the Persian leopard breeding habitats in northwestern Iran. Landscape patches are shown in Fig. 3.

	Alborz landscape	Boundary landscape		Total
	Patch 1	Patch 2	Patch 3	
Area (km^2)	18,055.9	1712.0	259.0	20,026.9
Protected by CAs in km^2 (%)	2025.5 (11.2)	931.2 (54.4)	236.6 (91.3)	3193.3 (15.9)
Protected by NHAs in km^2 (%)	2671.2 (14.8)	102.6 (6)	0	2773.8 (13.8)

CA: Conservation areas include national park, protected area and wildlife refuge.
NHA: No Hunting Area is a protection category which aims to halt poaching, but has no guarantee against development plans.

2004; CLWG, 2014) despite multiple records of adult females in southern Azerbaijan (Avgan et al., 2012; Askerov et al., 2015).

4.2. Connectivity and fragmentation

Based on a sample of leopard occurrence records across the Iranian Caucasus Eco-region, our model showed that the northwest of the country harbors two main suitable landscapes which largely accord with the results of previous models (Zimmermann et al., 2007; Gavashelishvili and Lukarevskiy, 2008). Around 30% of these suitable habitats are already officially protected and probably function as regional population nuclei. However, only approximately half of the area suitable for leopards was completely protected according to the criteria published by the International Union for Conservation of Nature (IUCN). There is a serious risk of fragmentation within and between both landscapes, making it a priority to protect them and to identify potential corridors. Habitat fragmentation has diminished the viability of other leopard populations (Dutta et al., 2013; Swanepoel et al., 2013).

Iran's boundary landscape as well as adjacent areas of southern Azerbaijan and Armenia reportedly host some 10 leopards in the so-called Zangezur–Kiamaky population (Askerov et al., 2015), and these few animals probably comprise the majority of leopards in the Lesser Caucasus Mountains. To preserve connectivity between these populations and ensure the viability of leopards in this landscape it is important to secure corridors between the Alborz and boundary landscapes, which necessitates safeguarding trans-boundary movement through southern Azerbaijan. In the past decade, three different individual male leopards have been confirmed in the area connecting these two landscapes, all adult males (two in Talysh Mountain, Azerbaijan; Askerov et al., 2015, one shot in Germi Ardebil, Iran).

Others have emphasized the importance to leopards within the Lesser Caucasus of dispersal from northern Iran (Khorozyan and Abramov, 2007; Breitenmoser et al., 2010). What is new in our model is the conclusion that even Iran's boundary population is unlikely to remain viable without the critical connection with Alborz, through the Talysh Mountains within the extreme southeast of Azerbaijan (Zimmermann et al., 2007) where leopards are confirmed to exist (Askerov et al., 2015). Furthermore, recent records in Azerbaijan and Armenia are predominantly near the Iranian border (Khorozyan et al., 2008; Avgan et al., 2012; Askerov et al., 2015), again emphasizing the importance of trans-boundary cooperation between Iran and its northwestern neighbors.

4.3. Management implications

To maximize the chance of Persian leopards surviving in the Lesser Caucasus Mountains we suggest that the boundary landscape, including Arasbaran, Kiamaki, Dizmar and Marakan reserves, needs to be considered as a single management unit within which inter-connectivity should be secured. Happily, much of the suitable habitat in this landscape are protected, so the emphasis should turn to enforcing anti-poaching efforts to secure a stable prey population.

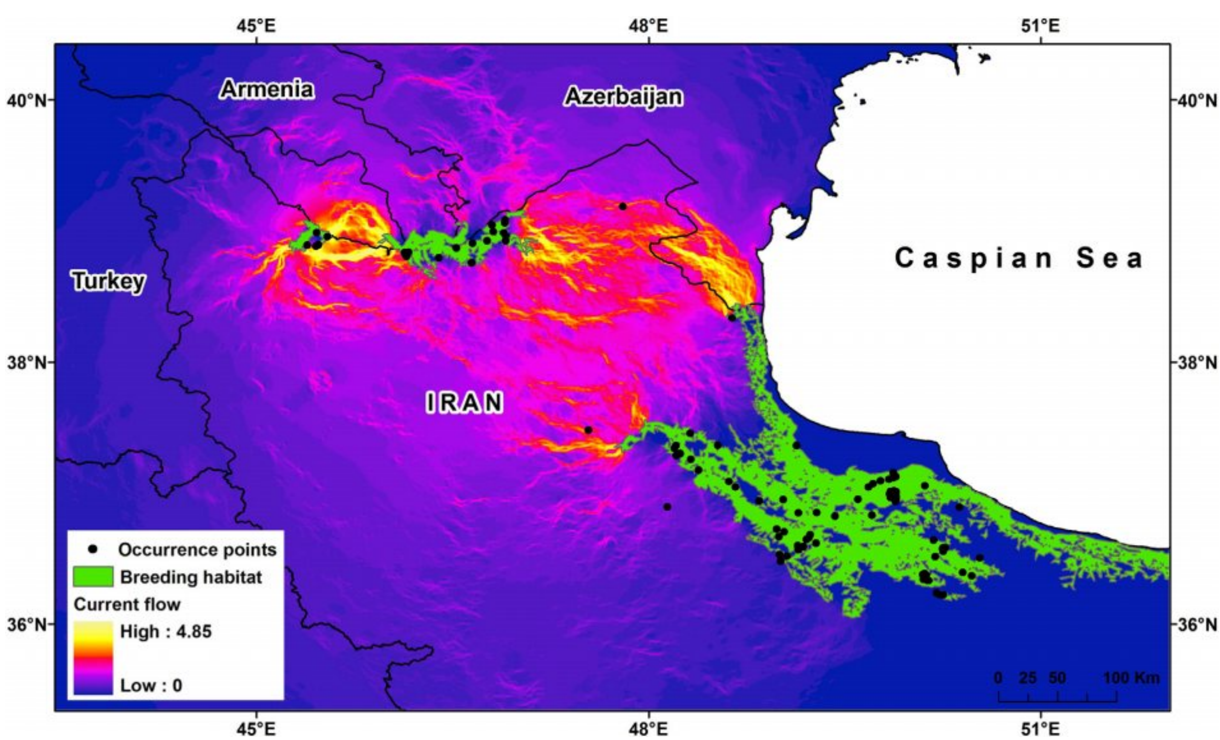

Fig. 4. Model of cumulative current flow used to evaluate habitat connectivity for Persian leopard across the Caucasus Eco-region.

Within the larger Alborz landscape areas suitable for leopards appear to be contiguous; however, confirmed records of leopards within this landscape are mostly confined to fragmented CAs. The gaps between them, particularly in the Alborz patch, need further protection to increase the proportion of suitable habitats safeguarded. In this regard, the top priority is Gilan province, because there a high proportion of potential corridor habitat is currently unprotected. A first step could be the designation of 'No Hunting Areas', where the main objective is to empower anti-poaching measures. Further, existing No Hunting Areas could be up-graded to Protected Areas or National Parks, to secure the habitats as well as the prey. Depletion of wild ungulates, leading leopards to prey more on domestic stock, has exacerbated conflict, particularly in Gilan (Babrgir et al., in press) and Qazvin (Khosravi et al., 2012). In these areas careful attention should be given to mitigating conflict between the leopards and local people (Dickman et al., 2011).

Although our findings shed light on the distribution of Persian leopards, and the connectivity of the landscape they occupy, little is known of their abundance. Ability to plan for their conservation would be greatly improved if numbers of Persian leopards, and indeed of their prey, could be ascertained. Viability of small and isolated populations of ungulates can be affected by dynamic demographic interaction between prey and predator (see e.g. Lovari et al., 2009).

Meanwhile, the most urgent priority is to control poaching to safeguard breeding sites. Significant investment into the conservation of the leopard is justified as this charismatic large cat is both an umbrella species – its conservation will also include the preservation of the prey species and their habitats – and a flagship species, a combination which Macdonald et al. (submitted) argue is particularly potent for conservation. Indeed, as Breitenmoser et al. (2007) also anticipated the leopard is arguably the most effective mammalian conservation ambassador, and we conclude that the Persian leopard is the ideal ambassador (sensu Macdonald et al., submitted) for conservation in the Caucasus, at the varied scales of attracting the support of the local population, between range states, and within the international conservation community.

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Appendix A. Supplementary data

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