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Habitat suitability, core habitats and diversity hotspots for the conservation of the mustelid species in Iran

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ABSTRACT

The process of habitat loss and fragmentation is inevitable with increasing human activities, necessitating conservation for the areas with the highest priorities (i.e., biodiversity hotspots). This study aimed to predict the core habitats of the eight mustelid species (family: Mustelidae) in Iran and detect mustelid diversity hotspots based on the highest species richness of these species to compare them with available conservation areas (CAs). Accordingly, habitat suitability modeling was carried out for each mustelid species through an ensemble approach, and species richness and mustelid diversity hotspots were determined by overlaying the predicted core habitats. The results revealed that the highest richness of the mustelid species was six species for the overlaid map of the modeled core habitats. The main mustelid diversity hotspots were along the Alborz Mountains and the Hyrcanian forest of northern Iran. There were some other hotspots along the Zagros Mountains in western Iran. CAs protected less than half of mustelid diversity hotspots, which means that wildlife managers should take into consideration the conservation action plan for the mustelid species in Iran. Besides, it is necessary to expand available CAs or establish new-targeted CAs according to mustelid diversity hotspots.

1. Introduction

With the daily increase in human activities, the process of habitat loss and fragmentation is inevitable, necessitating the conservation of the remaining fragmented core habitats for mammals, particularly carnivores (Bennett, 2003; Berger et al., 2008; Murphy et al., 2017). However, the available conservation areas (CAs, legally protected for biodiversity conservation in different categories of protection (Lausche and Burhenne-Guilmin, 2011)) are small or are not potentially appropriate for the conservation of carnivores (Cushman et al., 2013; Mohammadi et al., 2018). It is almost difficult to detect the core habitats of carnivores because these species are mainly nocturnal with cryptic behavior (Van der Hoeven et al., 2004; Zeller et al., 2011). In such circumstances, habitat suitability models (HSMs) (Guisan and Zimmermann, 2000) with a few occurrence data and available related environmental layers can predict core habitats of carnivores in order to manage activities, including expansion of available CAs or detection of new CAs. Several studies on habitat suitability of different carnivores in Iran (e.g., Ahmadi et al., 2020; Almasieh et al., 2016, 2019a, 2022; Ashrafzadeh et al., 2018, 2020; Ebrahimi et al., 2017; Farashi and Erfani, 2018; Farhadinia et al., 2015; Kaboodvandpour et al., 2021; Khosravi et al., 2018, 2019; Mohammadi et al., 2021a, 2022) have acknowledged experiences of habitat degradation and fragmentation and the needs for conservation of the remaining core habitats (for members of Felidae, Canidae, Hyaenidae and Ursidae families). However, few studies have been carried out on other carnivores in Iran, such as Mustelidae family (e.g., Farashi and Shariati, 2017; Sharifi et al.,

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2020).

Sixty-four mustelid species (order: Carnivora; Family: Mustelidae) have been identified in the world so far (IUCN (International Union for the Conservation of Nature and Natural Resources), 2022), of which eight species inhabit Iran (Table 1). Mustelidae, similar to the Felidae family, has the largest number of carnivorous species in Iran (Karami et al., 2015). Five mustelid species are categorized as least concern (LC), one species as near threatened (NT), and two species as vulnerable (VU) (IUCN (International Union for the Conservation of Nature and Natural Resources), 2022) (Table 1). Based on the classification of carnivores (< 7 kg as small, 7–25 as a medium, and > 25 as large) (Mills and Harvey, 2001; Ray et al., 2005; Holmern and Røskaft, 2013), two species of otters and two species of badgers in Iran are classified as medium-sized, and the remaining as small-sized carnivores (Table 1).

The selection of areas with the highest priorities of conservation (i.e., biodiversity hotspots) needs consideration due to limited resources and budgets (Farashi and Shariati, 2017; Myers et al., 2000). Species richness (i.e., the number of species in the unit of area) (Ceballos and Ehrlich, 2006) have been widely used to detect biodiversity hotspots (Reid, 1998; Cincotta et al., 2000; Ceballos et al., 2005). The species richness map is created by overlying core habitats generated through the habitat modeling of the mustelid species (Garcia, 2006) to determine the areas with the highest number of species richness as biodiversity hotspots (Ficetola et al., 2012). Biodiversity hotspots are given priority due to the coverage of more species (Farashi et al., 2017). Consequently, the expansion of existing or the establishment of new CAs can occur according to these hotspots with more certainty (Araújo et al., 2011; Meller et al., 2014; Almasieh et al., 2019b).

The mustelid species are unknown carnivores, and little information is available on their status and distribution in Iran (Karami et al., 2015). Detecting core habitats can illuminate the habitat status of the mustelid species, and wildlife managers can consider their biodiversity hotspots for conservation priorities in Iran. Considering all these details, the current study had four main objectives: (1) investigating habitat suitability and detecting core habitats for the mustelid species in Iran, (2) generating a species richness map, (3) detecting mustelid diversity hotspots based on the areas with the highest species richness of the mustelid species, and (4) comparing mustelid diversity hotspots with available CAs to suggest the expansion or establishment of new-targeted CAs.

2. Materials and methods

2.1. Study area

Iran, a country in southwestern Asia (with an area of about 1.648.000 km^2), has three different zoogeography regions, including Palearctic, Sahara-Arabian, and Oriental (Karami et al., 2008; Yusefi et al., 2019). Iran has two relatively distinct topographic situations: (1) mountainous areas, mainly including the Alborz and the Zagros Mountains, and (2) vast arid plains in the center and south of the country (Mohammadi et al., 2021a). About 190 mammal species inhabit Iran (Karami et al., 2008, 2015; Yusefi et al., 2019), 31 of which belong to Carnivora order (two felids are extinct) (Karami et al., 2015; Yusefi et al., 2019). The number of carnivore species in Iran is about half of the number of carnivore species in the Indian subcontinent and approximately equals the number of carnivore species in Europe (Karami et al., 2015). CAs protect about 16.5% of the areas of Iran (Fig. 1). The Hyrcanian forests of northern Iran and most of the mountainous areas (mainly the Alborz and the Zagros Mountains) are situated in two global biodiversity hotspots of Irano-Anatolian and Caucasus (Mittermeier et al., 2005) (Fig. 1).

2.2. Data collection

Occurrence records of the eight mustelid species in Iran were collected from the Department of Environment (DoE) game wardens, and Iranian wildlife research papers and reports. DoE has applied provincial management for the CAs and other free areas. Therefore, the obtained mustelid occurrence records were checked according to provincial DoE and other related reliable sites and news (e.g., https://iranmammalrecords.fireblog.ir/). A radius of 5 km (Sharifi et al., 2020) was considered around each occurrence records for

Table 1
Properties of the mustelid species in Iran, including conservation properties and the number of occurrence records.

Mustelid species		Conservation category (IUCN Red List)	Number of occurrence records (during 2010–2020)
Common English name	Scientific name		
Least weasel[a]	*Mustela nivalis* Linnaeus, 1766	LC	48
Beech marten (Stone marten)[a]	*Martes foina* Erxleben, 1777	LC	83
Pine marten[a]	*Martes martes* Linnaeus, 1758	LC	19
Eurasian otter[b]	*Lutra lutra* Linnaeus, 1758	NT	100
Smooth-coated otter[b]	*Lutrogale perspicillata* I. Geoffroy Saint-Hilaire, 1826	VU	3
Marbled polecat[a]	*Vormela peregusna* Guldenstadt, 1770	VU	52
Eurasian badger[b]	*Meles meles* Linnaeus, 1758	LC	81
Honey badger[b]	*Mellivora capensis* Schreber, 1776	LC	43

[a] Small carnivores.
[b] Medium carnivores.

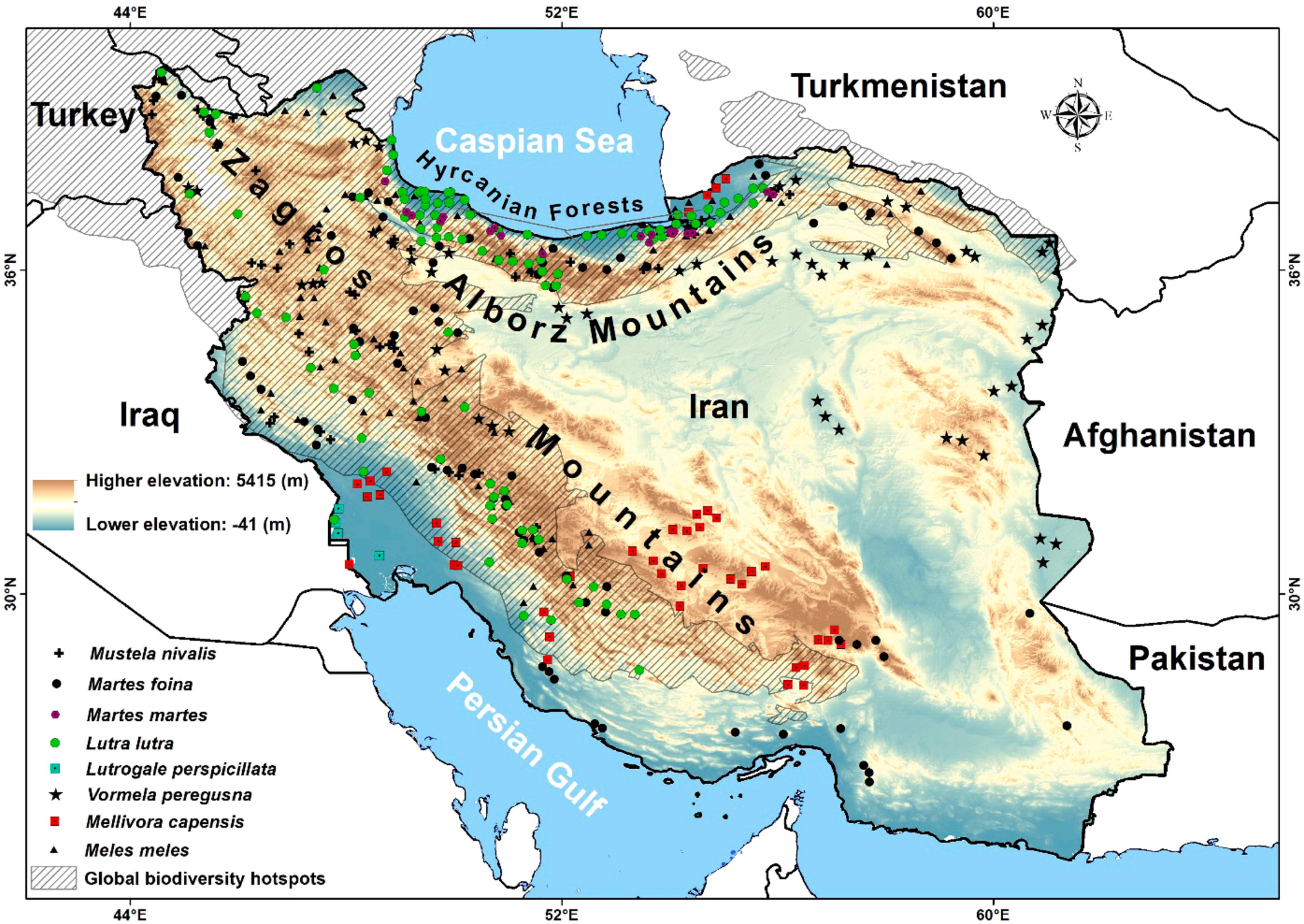

Fig. 1. Study area and occurrence records of the mustelid species in Iran.

spatial filtering using the Spatially Rarify Occurrence Data tool in the SDMtoolbox to minimize spatial-autocorrelation for each species (Brown, 2014).

2.3. Environmental variables

All related environmental variables (n = 33), including topographic, climatic, land-cover, water resources, safety and protection, and human disturbance, were primarily considered for habitat modeling of the eight mustelid species (Supplementary Table S1). Digital Elevation Model (DEM, as the elevation variable), derived from the 30-m Shuttle Radar Topography Mission (SRTM, downloaded from http://earthexplorer.usgs.gov), was implemented to calculate slope and aspect variables using the Surface tool. DEM was used to create topographic roughness variable (standard deviation of elevation value of DEM cells in the 5-km neighborhood, Farhadinia et al., 2015) using the Neighborhood tool. Nineteen climatic variables were selected to predict the distribution of the mustelid species (http://worldclim.org; Fick and Hijmans, 2017).

A circle-moving window with a 5-km radius was used to create density maps of three cover types, including forests, rangelands, and agricultural lands, derived from the land-cover map of Iran (FRWMO (Forest, Range and Watershed Management Organization of Iran), 2010). Normalized Difference Vegetation Index (NDVI) was created by the 16-day composite MODIS data (MOD13A1 V6 map at 500-m cell size; http://earthexplorer.usgs.gov) according to the mean values for the year 2020. Given the importance of water resources for carnivores (Almasieh et al., 2019a) and the dependence of otters on wetlands, distance to rivers (DoE (Department of the Environment of Iran), 2018) and distance to wetlands (DoE (Department of the Environment of Iran), 2018) were also included in habitat modeling of the mustelid species using the Euclidean Distance tool. As the CAs support carnivores from hunting and other anthropogenic disturbance (Almasieh et al., 2022), distance to CAs (DoE (Department of the Environment of Iran), 2018) was created as a surrogate of safety and protection. Human footprint (Venter et al., 2016, 2018), an indicator of population density, human access, and infrastructures (Sanderson et al., 2002), was used as the human disturbance variable. Given the adverse effects of human settlements and roads on carnivores (Mohammadi et al., 2018), distance to villages (DoE (Department of the Environment of Iran), 2018) and distance to roads (DoE (Department of the Environment of Iran), 2018) were considered two other anthropogenic variables for habitat modeling of the mustelid species in the study area. All variable layers were created with a 1-km resolution using tools available in ArcGIS software version 10.3.

First, the MaxentVariableSelection package (Jueterbock, 2015) in R version 3.6.0 (R Core Team, 2019) was employed to exclude variables by setting a contribution threshold of 5%, regularization multiplier of 1–5 with increments of 0.5, and inter-correlation of 0.7 to reduce multicollinearity among variables and choose the best variables for each mustelid species. Variables with the highest Area under the Curve (AUC) of Receiver Operating Characteristic (ROC) and the lowest Akaike Information Criterion (AIC) were chosen. The second method to reduce multicollinearity among variables was the Variance Inflation Factor (VIF) of the dataset, checked using the USDM package (Naimi et al., 2014) in R, to exclude variables (selected in the previous step) with VIF $>$ 3 (threshold suggested by Zuur et al., 2010) (Supplementary Table S2).

2.4. Habitat modeling

The smooth-coated otter only occurred in the Hoor-Al-Azim wetland in southwest of Iran, while some occurrence reports from other adjacent areas were not confirmed (Karami et al., 2015; Yusefi et al., 2019). Given the low number of available occurrence records and small occurrence areas, this wetland was considered the whole occurrence area of smooth-coated otter in Iran, and habitat modeling was not carried out for this species. An ensemble modeling approach was used to predict the habitat suitability of the remaining mustelid species in Iran using the R package biomod2 (Thuiller et al., 2019). The ensemble model increases accuracy by combining predictions of different models and fitting several suitability models rather than a single model with an uncertain prognosis (Araújo and New, 2007; Shahnaseri et al., 2019). Among 10 prediction models implemented in biomod2, three machine learning models, including Random Forest (RF), Maximum Entropy (MaxEnt), and Generalized Boosting Model (GBM), were applied for habitat modeling of each mustelid species in Iran. The accuracy of each model for each species was checked by AUC and True Statistic Skill (TSS) (Eskildsen et al., 2013). According to the method used by Kaboodvandpour et al. (2021), 190–1000 pseudo-absence points were randomly created across the whole study area and outside of the 5-km radius circle around each occurrence records of each species. The analyzes were carried out by applying 20 replicates for each modeling approach to obtain conservative results. In addition, a prevalence of 0.5 (the exact weights of occurrence and pseudo-absence points) was considered (Calambás-Trochez et al., 2021). The mean variables' contribution of three models for each species was calculated in Biomod2. Besides, response curves of occurrence records to the variables for GBM model of each mustelid species were determined in the study area.

2.5. Core habitats, species richness and mustelid diversity hotspots

The ensemble suitability maps of the mustelid species were converted into the resistance maps according to the methods introduced by Mateo-Sánchez et al. (2015) and Wan et al. (2019). Core habitats for each mustelid species were predicted using Universal Corridor (UNICOR) software (Landguth et al., 2012) and resistant kernels method, which is an algorithm calculating the resistance

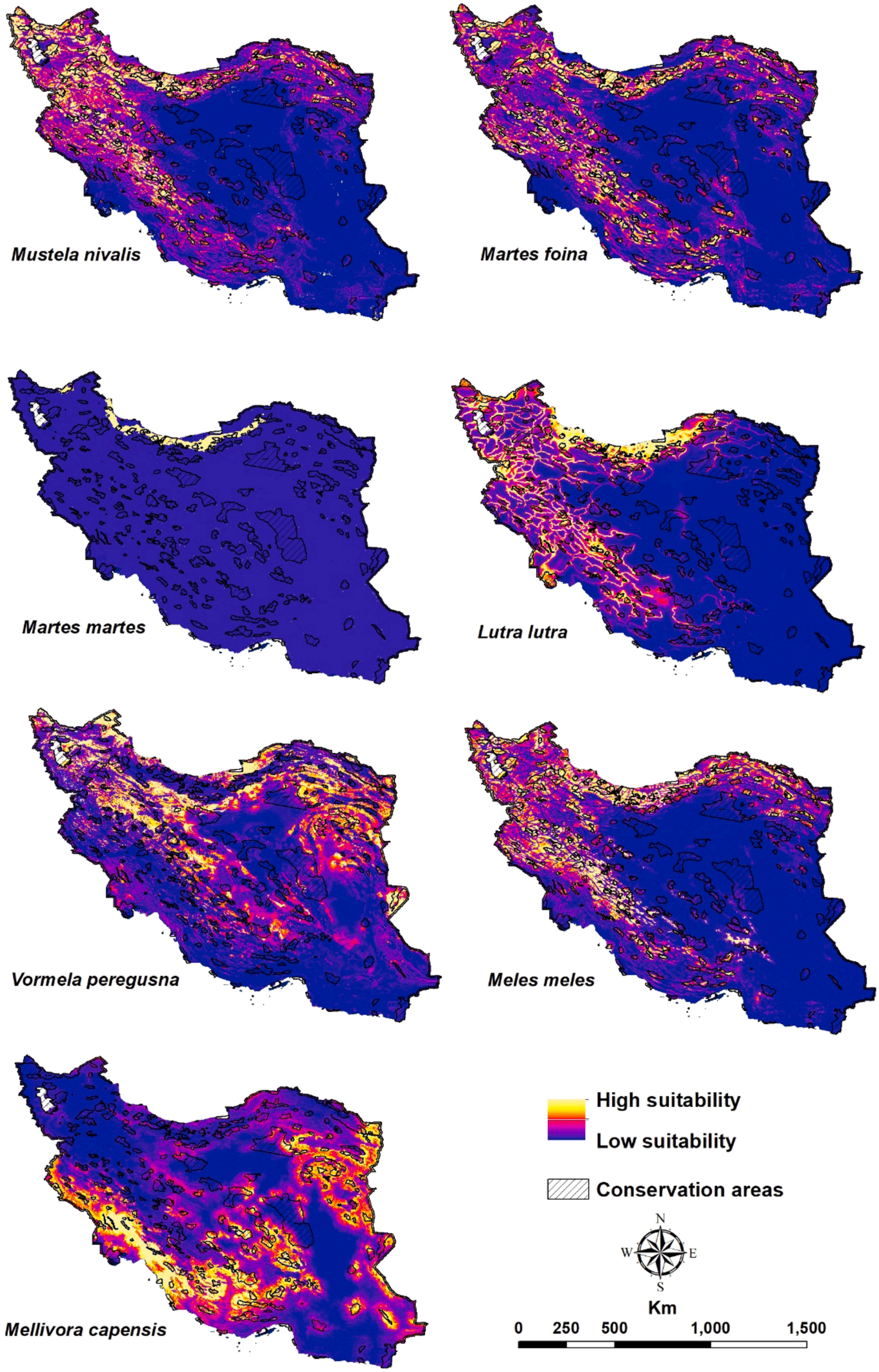

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Fig. 2. Ensemble suitability maps of the mustelid species in Iran.

cost-weighted dispersal around each occurrence record up to a dispersal threshold defined by the user (Compton et al., 2007; Mohammadi et al., 2021b). Generally, the density and the number of occurrence records, the dispersal ability of the species, and the resistance of the landscape determine the rate of organism movement through the landscape (Cushman et al., 2013). Researchers have carried out different studies on the home ranges of the mustelid species (e.g., King, 1975; Zalewski et al., 1995; Santos and Santos-Reis, 2010; Quaglietta, 2012; Begg et al., 2005; Gaughran et al., 2018; https://kids.kiddle.co/Marbled_polecat). Based on the body size and the ability of movement, the movement distance of 50 km was considered for *Mustela nivalis*, *Martes foina*, *Martes martes* and *Vormela peregusna*, and 70 km for *Lutra lutra*, *Meles meles* and *Mellivora capensis*. The contiguous core habitat map of each mustelid species was converted to a categorical map based on > 10% of the highest records for the species (Cushman et al., 2013).

The core habitats of the mustelid species were overlaid to obtain the species richness of the mustelids in Iran. The cells with a higher number of mustelid species represent higher species richness and vice versa. Ceballos and Ehrlich (2006) considered 2.5%, 5%, 20% and 40% of the highest number of species richness as mammal biodiversity hotspots. Based on this study and according to the objectives of DoE to increase CAs from 16.5% to 20% of the area of Iran (Almasieh et al., 2019b), about 2.5% and 5% of the highest number of species richness of the mustelid species were regarded as mustelid diversity hotspots. Shapefiles of two global biodiversity hotspots (i.e., Irano-Anatolian and Caucasus) were downloaded from https://www.cepf.net/our-work/biodiversity-hotspots/hotspots-defined to calculate the coverage of mustelid diversity hotspots with these two global biodiversity hotspots. Finally, the coverage of mustelid diversity hotspots with CAs was calculated, and no protected parts of core habitats were recommended as new CAs. The coverage was also calculated for each mustelid species separately.

3. Results

A total of 429 reliable occurrence records were obtained for the eight mustelid species in Iran from 2010 to 2020 (Table 1, Fig. 1). Spatial filtering excluded nonoccurrence records.

3.1. Variables contribution and preferences

Based on the MaxentVariableSelection results and VIF < 3, different optimal variables were chosen for the habitat modeling of the mustelid species in Iran (Supplementary Table S2). AUC and TSS were > 0.9 and > 0.7, respectively, for all models, indicating the strong performance of the all models (Supplementary Table S3). Based on the three selected models, the most influential variables (first to third ranks) were topographic roughness and distance to CAs (three times for each variable), and annual mean temperature (BIO1), min temperature of coldest month (BIO6), precipitation seasonality (BIO15) and NDVI (two times for each variable) (Supplementary Table S4). Other influential variables were temperature seasonality (BIO4), mean temperature of warmest quarter (BIO10), forests density, rangelands density, agricultural lands density, distance to rivers and distance to wetlands (once for each variable) (Supplementary Table S4). Supplementary Figs. S1–S7 and Supplementary Text S1 show the response curves of occurrence records to environmental variables of GBM models and explanations about them, respectively. Briefly, most of the species occurred in areas with 1000–2000 m altitude with moderate (e.g., *M. martes*) to high (e.g., *M. nivalis* and *M. foina*) topographic roughness, moderate (e.g., *M. foina* and *L. lutra*) to high (i.e., *M. martes*) vegetative cover, 10–20 °C mean annual temperature, and 200–600 mm annual precipitation. Cold toleration was different among the mustelid species from − 5 °C for *M. capensis* to − 15 °C for *M. nivalis*. In all mustelid species, the probability of occurrence decreased by increasing distance to CAs and rivers and increased by increasing distance to villages and roads.

3.2. Habitat suitability modeling and core habitats

Ensemble suitability maps of the mustelid species showed that the main areas with high habitat suitability occurred along the mountainous areas of Iran, particularly the Alborz and the Zagros Mountains and the Hyrcanian Forests in northern Iran (Fig. 2). Habitat suitability models of RF, MaxEnt and GBM mainly had a similar pattern for each mustelid species (Supplementary Figs. S8–S14). *M. foina*, *V. peregusna* and *M. nivalis* had the highest number of core habitats, *M. meles, L. lutra* and *M. capensis* had the largest core habitats, and *M. meles L. lutra* and *M. foina* had the largest areas of all the core habitats, respectively for the mustelid species in Iran (Table 2, Supplementary Fig. S15). More than 80% of core habitats for five mustelid species occurred in two global biodiversity hotspots of Irano-Anatolian and Caucasus (Table 2). CAs covered all the core habitats of *L. perspicillata*. For other mustelid species, CAs protected less than 43% of core habitats (Table 2).

3.3. Species richness and mustelid diversity hotspots

The highest species richness of the mustelid species was six species for the overlaid map of modeled core habitats (Fig. 3). The maps of mustelid diversity hotspots were created by ≥ 3 species (43,865.75 km^2, about 2.7% of the study area) and ≥ 2 species (98,649.67 km^2, about 6% of the study area) from species richness of core habitats (Fig. 4). The main mustelid diversity hotspots occurred along the Alborz Mountains and the Hyrcanian forest of northern Iran. Some other hotspots occurred along the Zagros Mountains. About 92% and 88% of mustelid diversity hotspots (2.7% and 6% of the study area) were covered by two global biodiversity hotspots of Irano-Anatolian and Caucasus, respectively. However, only about 43% and 35% of mustelid diversity hotspots (2.7% and 6% of the study area) were protected by available CAs, respectively (Fig. 4).

4. Discussion

This study was carried out on the relatively unknown carnivore family in Iran. Habitat fragmentation with different degrees of severity was confirmed for the mustelid species in Iran, while available CAs were not sufficient for conservation of their core habitats. Mustelid diversity hotspots occurred mainly along the Alborz Mountains, the Zagros Mountains, and the Hyrcanian Forest. CAs covered less than 50% of mustelid diversity hotspots in Iran.

Compared to other studies on the variables contribution in habitat modeling of some of the mustelid species, Sharifi et al. (2020) introduced annual mean temperature (BIO1) as the most important variable for habitat modeling of *M. capensis* in southern Iran. In our study, climatic variables were the second and third most important variables for this species. However, agricultural land density was the most important variable for habitat modeling of *M. capensis* in our study, unlike the study of Sharifi et al. (2020). Distance to rivers and distance to wetlands were the most important variables for habitat suitability of *L. lutra* in our study area, confirmed by the studies of Mirzaei et al. (2009) in northern Iran, Riley et al. (2020) in an area of Wales, and Shin et al. (2020) in an area of South Korea. A climatic variable was the third most important variable for habitat suitability of *L. lutra* in our study area, confirmed by the study of Jo et al. (2017) in an area of South Korea.

Compared to other studies on preferences of one mustelid species, *M. martes* preferred areas with moderate topographic roughness and high density of forests in our study area, confirmed by the studies of Kurki et al. (1998) and Brainerd and Rolstad (2002) in different areas of Scandinavia. However, Lombardini et al. (2015) reported very rocky areas with shrublands and woodlands for *M. martes* in an area of Italy, which is inconsistent with results of our study.

Habitat fragmentation occurred for the mustelid species in Iran, especially for *M. foina*, *V. peregusna* and *M. nivalis*, with the highest number of fragmented core habitats. Farashi et al. (2017) reported the severity of habitat fragmentation for threatened and near-threatened mammals in Iran, also confirmed in our study, particularly for vulnerable species *V. peregusna*. The available CAs protected less than half of the core habitats for the mustelid species (except for *L. perspicillata* with 100% protection). According to the study by Farashi et al. (2017), *V. peregusna* had the lowest protection of core habitats among the threatened and near-threatened mammals in Iran, as confirmed in our study (the lowest protection of core habitats by available CAs among the mustelid species). *M. capensis* had the second-lowest protection of core habitats by available CAs in our study, confirmed by the study of Sharifi et al. (2020). Wildlife managers should notice large core habitats for conservation to prevent further habitat patchiness, especially for *M. meles*, *L. lutra*, and *M. capensis*.

Yusefi et al. (2019) introduced the Alborz and the Zagros Mountains as areas with the highest species richness of mammals in Iran. Farashi et al. (2017) confirmed their results and also introduced northern Iran as a biodiversity hotspot for the threatened and near-threatened mammals in Iran. Our results confirmed the mentioned studies and mustelid diversity hotspots occurred in these areas. Farashi et al. (2017) reported 57% coverage of core habitats with available CAs for the threatened and near-threatened mammals in Iran. In our study, CAs protected less than half of mustelid diversity hotspots. This means that the conservation action plan for the mustelid species needs reconsideration in Iran. As some mustelid species in Iran were threatened by human activities (habitat loss and poaching for their furs or because of conflicts) (Karami et al., 2015), and given that establishing more CAs is a challenge for wildlife managers, we strongly recommend the establishment of new CAs with less strictness, such as No-Hunting Areas (to limit human activities such as poaching and habitat changes). The occurrence of mustelid diversity hotspots in two global biodiversity hotspots of Irano-Anatolian and Caucasus indicate that they have been well defined, and directing the conservation focus toward them would mainly protect the global biodiversity.

Table 2
Properties of core habitats for each mustelid species in Iran.

Species	Number of cores	Area (km^2)		Percentage of coverage	
		The largest patch	All	CAs	Global biodiversity hotspots
Mustela nivalis	18	5780.09	39,798.64	42.04	97.81
Martes foina	23	8673.74	79,730.69	39.78	86.54
Martes martes	3	9880.04	17,716.2	26.88	100
Lutra lutra	11	32,396.66	86,154.67	25.51	88.53
Lutrogale perspicillata	2	311.06	529.76	100	0
Vormela peregusna	19	8263.58	74,148.61	13.37	32.69
Meles meles	14	39,807.79	127,687.62	30.42	91.35
Mellivora capensis	8	13,437.69	70,295.83	17.62	42.72

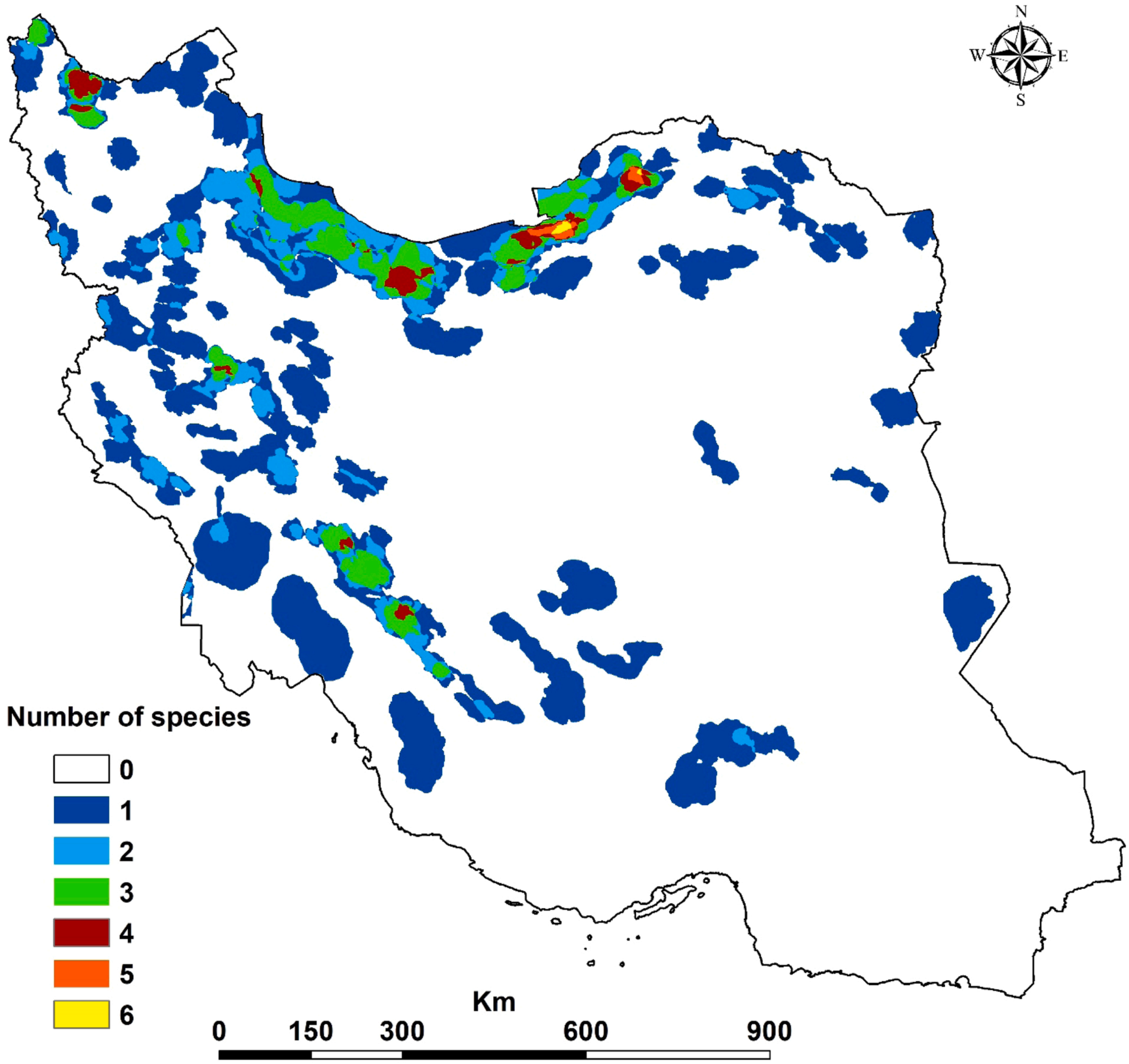

Fig. 3. Species richness of modeled core habitats for the mustelid species in Iran.

5. Conclusion

This study introduced habitat requirements and diversity hotspots of the mustelid species in Iran. Wildlife managers should consider mustelid diversity hotspots in Iran for the expansion of available CAs or the establishment of new-targeted CAs. Protection of these small and medium-sized carnivores could result in the survival of vital food networks of wildlife and consequently sustain the entire biodiversity in Iran.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

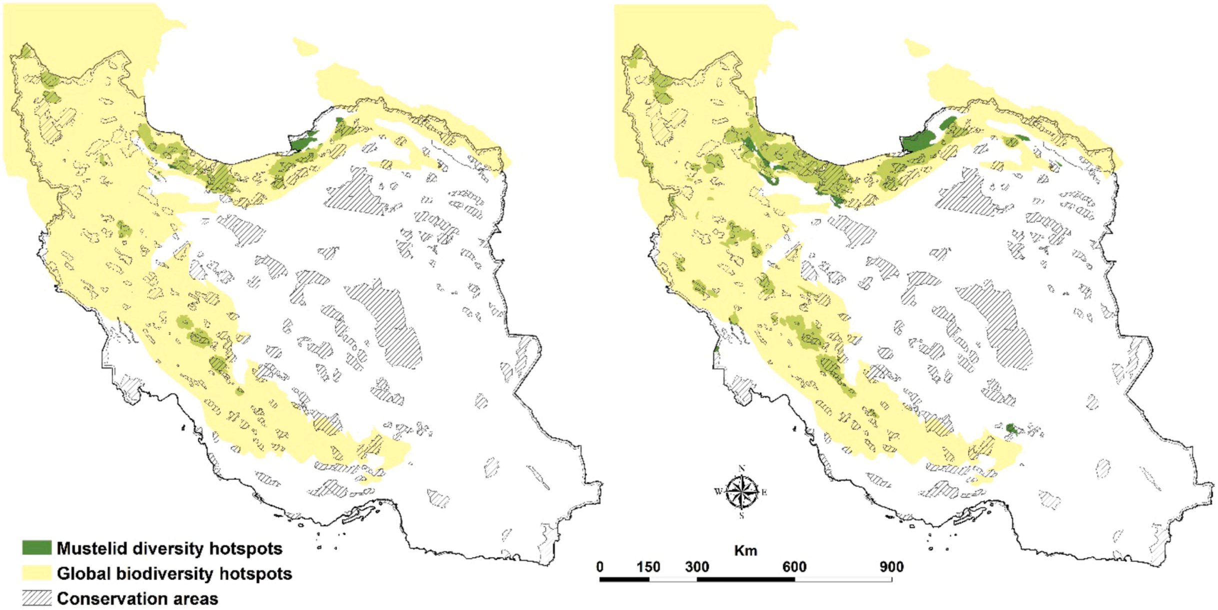

Fig. 4. Mustelid diversity hotspots based on the highest species richness of modeled core habitats in Iran (Right: 2.7% of the study area based on ≥ 3 mustelid species and Left: 6% of the study area based on ≥2 mustelid species).

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CRediT authorship contribution statement

K.A. conceptualized and designed the project. **K.A.** collected the data. **K.A. and M.C.** analyzed the data and interpreted results. **K. A. and M.C.** wrote the manuscript. **K.A. and M.C.** discussed the results and commented on the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02120.

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