Mammalian Biology 87 (2017) 71–88

Contents lists available at ScienceDirect

Mammalian Biology

journal homepage: www.elsevier.com/locate/mambio

Original investigation

Identifying biodiversity hotspots for threatened mammal species in Iran

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ARTICLE INFO

Article history:
Received 4 February 2017
Accepted 19 June 2017
Handled by Danilo Russo
Available online 21 June 2017

Keywords:
Conservation
Habitat
Model
Protected area
SDMs

ABSTRACT

Conservation biology has much more attention for biodiversity hot spots than before. In order to recognize the hotspots for Iranian terrestrial mammal species that are listed in any red list, nationally or globally, ten Species Distribution Models (SDMs) have been applied. The SDMs evaluation results based on the TSS and AUC values showed that all ten models of habitat suitability perform significantly better than the random selection for all studied species. According to the results, biodiversity hotspots for threatened mammal species are located in north, west and central of Iran, along the Zagros and Alborz mountain range. Therefore, habitats for threatened mammal species have been limited to small parts of Iran (approximately 27% of the country). These areas are severely fragmented and only 57% of them have been announced protected by the current conservation system. The suggestion is that, as the sustainability of these habitats would strongly depend on maintaining dispersal corridors to facilitate the movement of animals among the habitat fragments, conservation efforts should focus on those hotspots which are not formally protected under conservation laws.

Introduction

For more than 60 years, global biodiversity loss have been a major international concern (Hoffmann et al., 2011; Domisch et al., 2011). Some anthropogenic factors such as introduced invasive species, land use/cover change, and climate changes threat biodiversity. The Living Planet Index (WWF and GFN, 2014) mentioned that Habitat destruction or degradation due to land use/cover change is a crucial threat in 44.8% of the vertebrate populations, when climate change could outpace land use and land cover change as the greatest threat to biodiversity in the next decades (e.g. Bellard et al., 2012). Invasive species are considerable threats for ecosystems because of their ability to extinct and eliminate wild native species (Luque et al., 2014). Obviously, losing any species, either from fauna or flora, could have drastic effects on ecosystem functions (Worm and Duffy, 2003). Therefore, preserving world's biodiversity could be accomplished by focusing on biodiversity hotspots and conservation priorities (Myers et al., 2000; Dobson et al., 2006; Schmitz et al., 2010).

In past decades, researchers considered species richness to detect biodiversity hotspots (Brummitt and Lughadha, 2003; Orme et al., 2005). However, nowadays, more debates are directed on predicting species distribution and evolutionary information. Consequently, some approaches with the combination of phylogenetic methods and geographical distribution of species have been recommended (Huang et al., 2016). Recently, the species distribution models (SDMs) have become most fundamental techniques to identify biodiversity hotspots (Platts et al., 2008; Ko et al., 2014). SDMs have been developed to predict species distribution out of presence/absence data and became important part of ecological studies (Phillips et al., 2006; Royle et al., 2012; Yackulic et al., 2013; Renner and Warton, 2013; Bosso et al., 2016; Smeraldo et al., 2017). SDMs have been ranked as one of the top five research methods in ecological sciences (Renner and Warton, 2013).

The process of protected areas selection has been mostly based on their economic value and not their on conservative importance. According to the approach, effectiveness of protected areas for the conservation of biodiversity is questionable (Rodrigues et al., 2004). Recently, the biodiversity hotspots developed using SDMs has been applied to evaluate the effectiveness of protected areas as the gap analysis (Araújo et al., 2011; Meller et al., 2014). Therefore, The objectives of this study were to (1) use species distribution models to determine the suitable habitats for threatened mammal species in Iran, (2) use an ensemble-forecasting framework to overlay the suitable habitats of threatened mammal species and assign the biodiversity hotspots, and (3) evaluate whether the current

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http://dx.doi.org/10.1016/j.mambio.2017.06.002
1616-5047/

Table 1
Threatened mammal species and results of habitat modeling (SH: suitable habitats, PSH: protected suitable habitat, suitable habitats are located in protected area, TSS: True Skill Statistic for evaluating the model, AUC: Area Under Curve).

		Acinonyx jubatus (Schreber, 1775)	*Capra aegagrus (Erxleben, 1777)*	*Gazella Subgutturosa (Güldenstädt, 1780)*	*Hyaena hyaena (Linnaeus, 1758)*	*Lutra lutra (Linnaeus, 1758)*	*Otocolobus manul (Pallas, 1776)*	*Ovis orientalis (Gmelin, 1774)*	*Ovis Vignei (Blyth, 1841)*	*Panthera Pardus (Linnaeus, 1758)*	*Ursus thibetanus (Swinhoe, 1864)*	*Vormela peregusna (Güldenstädt, 1770)*	*Biodiversity hotspot*
Status	National	CR	VU	VU	NT	NT	NT	VU	VU	EN	CR	VU	–
	Global	VU	VU	CR	NT	NT	NT	VU	VU	VU	VU	VU	–
Presence records		38	260	44	57	102	24	64	61	137	71	27	
SH/PSH	PSH (%)	28.44	58.76	35.33	65.61	7.29	28.86	41.51	27.03	53.09	3.07	2.47	56.65
	PSH (ha)	4823556.41	9965706.40	5992682.66	11127032.08	1235877.06	4894646.74	7040000.29	4584985.54	9003380.41	521069.92	418410.56	9607899.22
	SH (%)	4.74	31.31	15.34	27.46	5.95	15.31	19.93	16.07	28.03	4.85	12.70	26.61
	SH (ha)	7678256.03	50721138.16	24841817.61	44480721.62	9645126.23	24808351.77	32284571.52	26028256.29	45405976.21	7849507.81	20571639.61	43112370.06
TSS	SRE	0.75	0.85	0.76	0.75	0.76	0.81	0.87	0.81	0.75	0.91	0.89	–
	RF	0.82	0.89	0.73	0.75	0.76	0.86	0.87	0.87	0.821	0.81	0.91	**-**
	MARS	0.81	0.86	0.81	0.92	0.82	0.83	0.82	0.84	0.86	**0.94**	0.88	–
	MaxEnt	**0.89**	**0.93**	**0.92**	**0.93**	**0.95**	**0.93**	**0.92**	**0.92**	**0.96**	0.84	0.8	–
	GLM	0.88	0.74	0.75	0.76	0.77	0.86	0.72	0.74	0.75	0.83	0.82	–
	GAM	0.80	0.80	0.81	0.86	0.85	0.70	0.82	0.81	0.82	0.86	0.75	–
	FDA	0.84	0.73	0.84	0.85	0.82	0.87	0.86	0.88	0.88	0.85	0.65	–
	CART	0.77	0.83	0.86	0.8	0.92	0.90	0.72	0.78	0.90	0.85	0.89	–
	BRT	0.82	0.73	0.72	0.76	0.70	0.82	0.84	0.89	0.88	0.80	0.70	–
	ANN	0.82	0.78	0.83	0.91	0.79	0.73	0.80	0.83	0.81	0.81	0.60	–
AUC	SRE	0.72	0.85	0.76	0.75	0.76	0.81	0.80	0.80	0.705	0.91	0.80	–
	RF	0.82	0.89	0.79	0.75	0.76	0.86	0.87	0.878	0.821	0.81	**0.91**	**-**
	MARS	0.81	0.86	**0.91**	0.92	0.82	0.85	0.84	0.83	0.80	0.89	0.80	–
	MaxEnt	**0.92**	**0.92**	0.82	**0.93**	**0.96**	**0.92**	**0.91**	**0.91**	0.81	**0.94**	0.80	–
	GLM	0.88	0.74	0.75	0.76	0.77	0.83	0.72	0.74	0.75	0.83	0.82	–
	GAM	0.80	0.80	0.81	0.86	0.85	0.80	0.82	0.81	0.82	0.86	0.85	–
	FDA	0.86	0.73	0.84	0.85	0.86	0.87	0.86	0.87	0.82	0.82	0.69	–
	CART	0.89	0.87	0.85	0.89	0.95	0.90	0.75	0.73	**0.92**	0.82	0.81	–
	BRT	0.88	0.74	0.78	0.73	0.72	0.88	0.87	0.86	0.82	0.81	0.82	–
	ANN	0.88	0.77	0.81	0.90	0.74	0.74	0.81	0.82	0.87	0.85	0.84	–

The best model with highest TSS and AUC value is in bold.

protected areas are suitably located in the biodiversity hotspots. We considered threatened mammal species as indicator to identify biodiversity hotspots in Iran. Furthermore, we interpreted areas with high suitability for threatened mammal species as biodiversity hotspots (Catullo et al., 2008; Doko et al., 2011; Russo et al., 2015).

Material and methods

Study area

As a bridge which connects oriental regions to African zoo-geographical regions (Mittermeier et al., 2011), the geographical position of Iran makes this country a very important corridor for animal movements and therefore an area with rich biodiversity potentiality. On the other hand, the presence of Zagros mountain range from northwest to almost southeast of Iran might act as a main geographic barrier against animal dispersal (Gholamifard, 2011; Hosseinzadeh et al., 2014). Also, Iran is a vast country with different types of climate, significant differences in elevation among various districts and varied geological formation which have led this country to have a rich biological diversity. In fact, this country possesses the most diversified biological regions among Asia's southwestern countries (Makhdoum, 2008). Approximately 8000 plant species, 535 bird species, 227 reptile species, 160 freshwater fish species, 710 marine fish species, 197 mammal species and 21 amphibians have been recorded in Iran. Ergo, it is necessary to designate territories as protected areas in Iran. However, from 1970 to 2014, the number of Iran's protected areas increased from 18 to 274, respectively, that indicates the importance of protection of natural environmental and biological resource in Iran (Department of Environment of Iran, 2015).

Species data

In this study, 11 species of Iran's mammal species (Table 1) that are listed as threatened (i.e. near threatened, vulnerable, endangered, critically endangered) on global (IUCN, 2016) and national (Karami et al., 2015) red lists. Species distribution data were obtained from atlases data (Karami et al., 2015), literatures or from signs that have been found such as footprint, trace, corpse, etc. The presence points were at the 1×1 km resolution. The Records were screened in ArcGis (version 10.3) for spatial autocorrelation using average nearest neighbor analyses and Moran's I test to remove spatially correlated presence data.

Environmental variables

Different environmental parameters were used in this study, including topographic variables, climatic variables, land cover/land use characteristics and vegetation variable (Table 2). Topographic variables were obtained from a digital elevation model (DEM) that was generated by the national cartographic center of Iran (NCC) at 100 m resolution. The climatic variables were acquired from world-clim-global climate data at a resolution of 30″ (~1 km), (http://www.worldclim.org). The highly correlated variables were eliminated using a cluster analysis. Therefore, the initial set of 19 climatic variables was reduced to two. The multicollinearity test was conducted using Pearson correlation coefficient (r) to examine the cross-correlation between variables. Then those variables with cross-correlation coefficient value higher than ±0.8 were excluded from the analysis. Land use/land cover data were obtained from the Iranian forests, range and watershed management organization (IFRWO) and Iranian department of environment. These land cover data was derived from 30 m Landsat Enhanced Thematic Mapper Plus (ETM+) imagery in year 2014. Normalized difference vegetation index (NDVI) was used as vegetation variable and extracted from 30 m Landsat TM imagery for year 2016. All environmental variables were in a grid format.

Table 2
Environmental variables considered for the distribution models.

Environmental variables	Unit
Topographic variables	
Altitude	m
Slope	°
Climatic variables	
Annual mean temperature	°C
Annual precipitation	mm
Land use/land cover variables	
Distance of settlements in urban area	m
Distance of settlements in rural area	m
Distance of Road	m
Distance of stream	m
Distance of River	m
Distance of lake	m
Distance of Dry farm	m
Distance of Irrigated farm	m
Distance of Forest	m
Distance of Woodland	m
Distance of Scrubland	m
Distance of Range area	m
Distance of Bare area	m
Distance of Rocky area	m
Distance of Protected area	m
Vegetation variable	
NDVI	–

Table 3
The SDM algorithms in biomod[2] used in this research and their required type of dependent variables.

SDM	Variable	Type	Reference
ANN	Artificial neural networks	P/A	Lek and Guégan (1999)
BRT	Boosted regression trees	P/A	Elith et al. (2008)
CART	Classification and regression trees	P/A	Vayssières et al. (2000)
FDA	Flexible discriminant analysis	P/A	Hastie et al. (1994)
GAM	Generalized additive models	P/A	Guisan et al. (2002)
GLM	Generalized linear models	P/A	Guisan et al. (2002)
MaxEnt	Maximum entropy	P/B	Phillips et al. (2006)
MARS	Multivariate adaptive regression splines	P/A	Friedman (1991)
RF	Random forest	P/A	Breiman (2001)
SRE	Surface range envelope	P/B	Busby (1991)

P: Presence; A: Absence; B: Background. MaxEnt and SRE generate a large number (default: ten thousand) of random background absence point locations (aka pseudo-absences).

Species distribution models (SDMs)

In order to develop the SDMs for the studied mammal species the Biomod[2] package (Thuiller et al., 2009, 2014) for R version 3.1.25 (R Core Team 2014) was used, applying 10 algorithms (Table 3). These methods can be classified in four categories: regression, machine-learning, classification and enveloping. Regression-based SDMs are generalized linear models (GLMs) and generalized additive models (GAMs) that build linear and non-linear relationships between species occurrence and environmental parameters, respectively. The machine-learning methods include artificial neural networks (ANN), boosted regression trees, (BRT), multivariate adaptive regression splines (MARS), maximum entropy (MaxEnt) and random forest (RF). These methods use training data to derive the environmental space of the species occurrence, directly. In the other hand, Classification methods

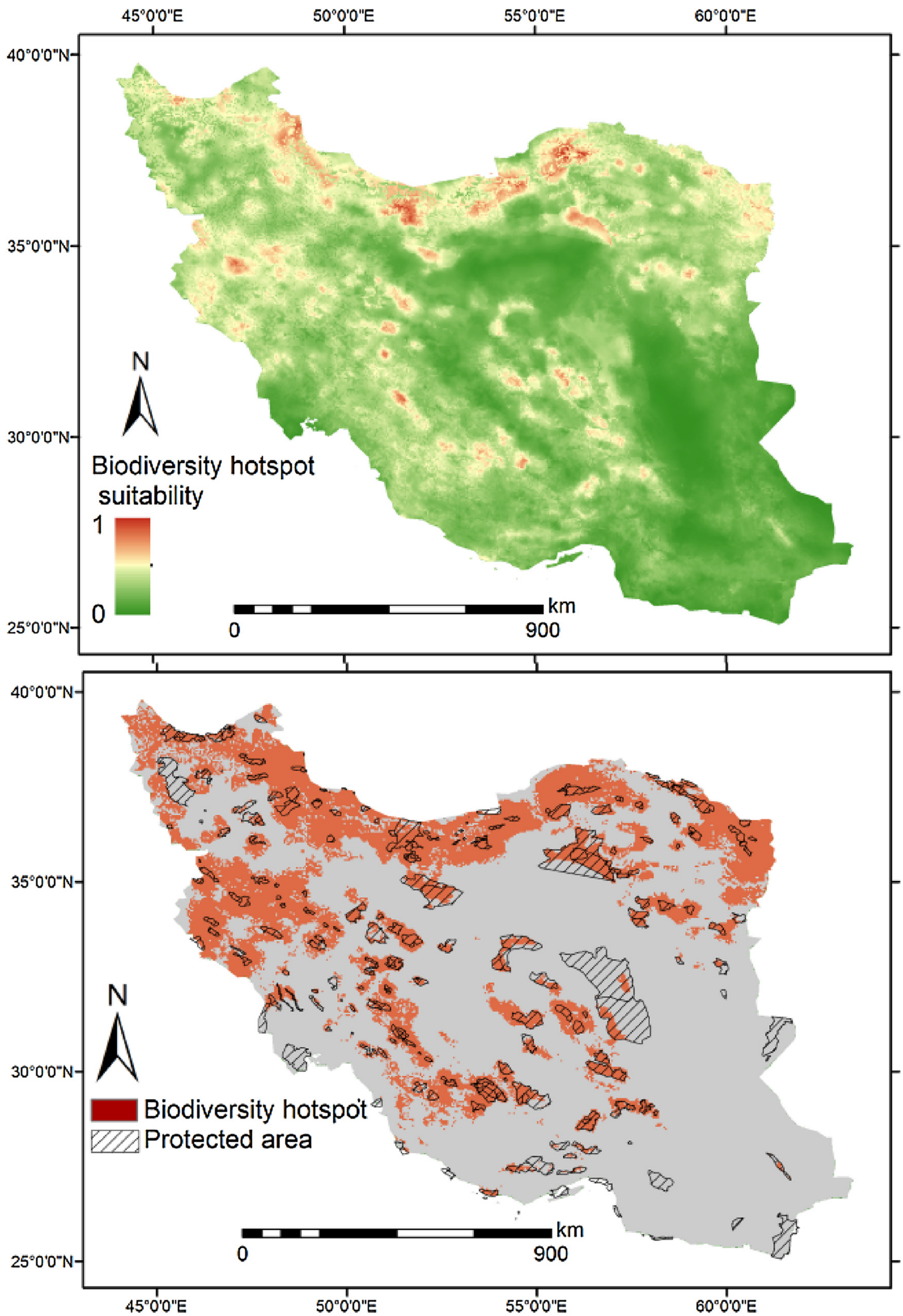

Fig. 1. Biodiversity hotspots in Iran and gaps between them and protected areas.

contain classification and regression trees (CART) and flexible discriminate analyses (FDA) that are based on consecutive data partitions into homogeneous groups of responses. Surface range envelope (SRE) is the enveloping method that describes the ecological conditions at the species occurrence points and extrapolates the results to similar areas (Elith and Leathwick, 2009; Franklin, 2010; Guisan and Thuiller, 2005; Merow et al., 2014).

Model validation

Model evaluation was based on different criteria: (1) the True Skill Statistic (TSS) which corresponds to the sum of sensitivity and specificity minus 1, and is independent of prevalence (Allouche et al., 2006), and (2) the area under the curve (AUC) (Fielding and Bell, 1997).

Hotspot definition and estimation

Biodiversity hotspots have been identified using an ensemble forecasting framework (Ko et al., 2014). In this case, we performed two kinds of overlap, including the continuous maps and binary maps. In order to perform that a linear combination was used, followed by a summation of the results to gain a suitability map (Eastman, 2001).

$$S = \sum_{i=1}^{n} W_i X_i$$

Where S is the suitability index of biodiversity hotspot, w_i is the TSS of predicted map for species i, n is the number of maps, and xi is the predicted map for species i.

To assess differences between predicted biodiversity hotspots and protected areas, the overlapping area among them were calculated. Hence, Iran's protected regions (defined as national parks, wildlife refuges, and protected landscapes) were used to analyze the effectiveness of protection. The number of pixels belonging to the predicted hotspots that were located in the protected areas was used to measure protection status (Ko et al., 2014).

Results

Forecasting species habitat suitability and biodiversity hotspots

The potential distribution maps of the best model for each species have been presented in Appendix A. The results showed that most of suitable habitats for mammal species are located in north, west and central of Iran (along the Zagros and Alborz mountain range). Iran's biodiversity hotspots map has been shown in Fig. 1. This figure illustrates north, north-west, west, north-east and central of Iran as regions with highest suitability for mammal species. These vast regions of suitable habitats contain high numbers of different ecosystems.

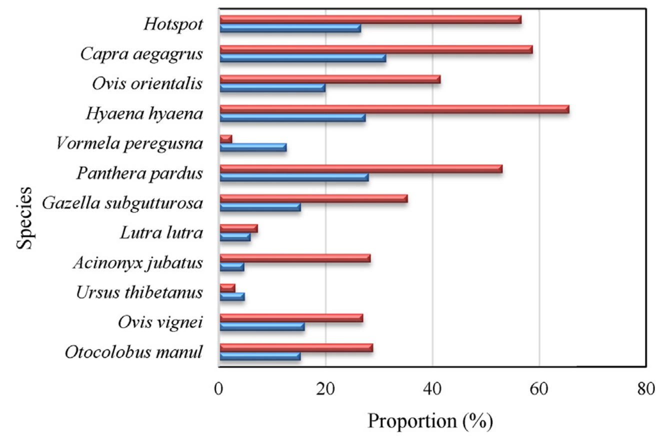

Fig. 2. Overlap between suitable habitat and protected areas (red bar: suitable habitats, blue bar: overlap between suitable habitats and protected areas). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The current overlap between suitable habitats and protected area has been shown in Table 1 and Fig. 2. The results show that only small parts of Iran are suitable for threatened mammal species. Furthermore, many of these species live in unprotected habitats. *Capra aegagrus* had the highest (31%) and *Acinonyx jubatus* had the lowest (4%) suitable habitat range among all studied species. Among species, the habitat of *Hyaena hyaena* had the highest overlap with protected areas (66%). In other hand, the lowest overlap between suitable habitats and protected area (2.47%) belonged to *Vormela peregusna*. Biodiversity hotspots cover almost 27% of the country where 57% of those hotspots were located inside the protected regions.

Overlaying land cover types on habitat probability map revealed that for most species suitable habitats have been located inside woodlands, forests and dry farms.

The most important environmental variables in predicting habitat suitability for most of these species were slope (16.8% of the contribution), NDVI (14.1% of the contribution), annual precipitation (8.4% of the contribution), annual mean temperature (7.3% of

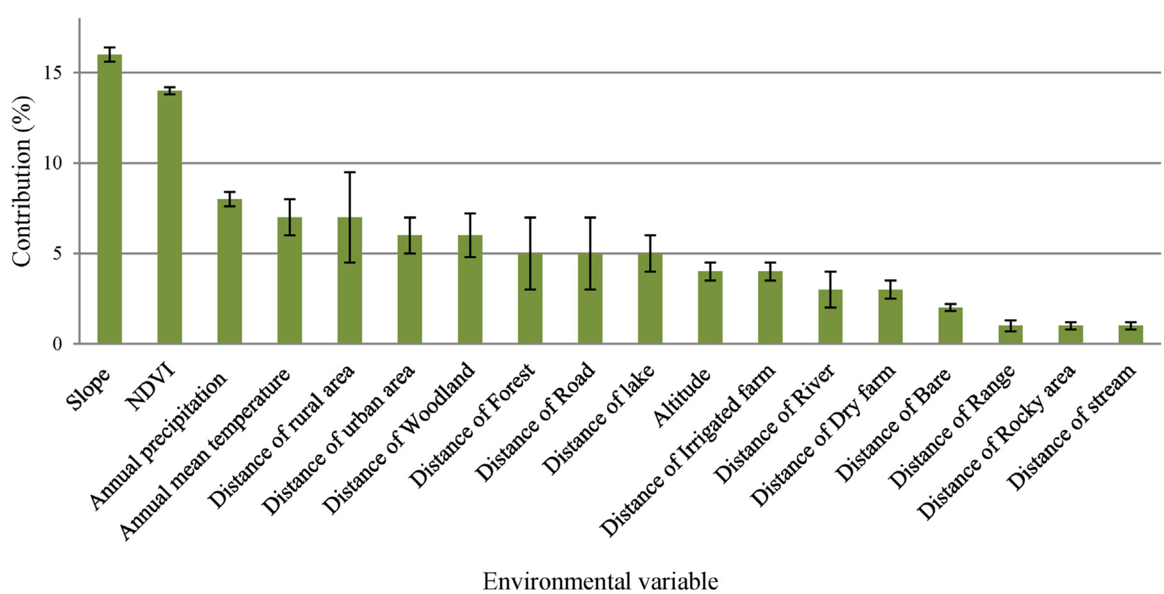

Fig. 3. Importance of environmental variables for all species.

the contribution), distance to rural area (7.1% of the contribution), distance to urban area (6.2% of the contribution) and distance to woodland (6.0% of the contribution) (Fig. 3).

Model validation

The modeling validation results based on TSS and AUC showed that all ten models perform significantly better than the random selection (Table 1). However, MaxEnt had the best performance for most species. The maximum TSS value (0.96) is reported for *Panthera Pardus* by MaxEnt model and the minimum TSS values (0.60) is for *Vormela peregusna* by ANN model. Also the maximum AUC value (0.96) is reported for *Lutra lutra* by MaxEnt model and the minimum AUC values (0.70) is for *Panthera Pardus* by SRE model.

Discussion

Forecasting species habitat suitability

This study represents an important dataset for threatened mammal species distribution in Iran that evaluates effectiveness of the protected area network in these species diversity. Many studies have been performed about gap analyses at the local scale (e.g. Farashi et al., 2016) but based on the literature reviews no comprehensive gap analysis has ever been performed for the whole country. Moreover, species distribution modeling has been applied at national scale in Iran (e.g. Farashi and Najafabadi, 2015) and in other continents (e.g. Catullo et al., 2008), but no systematic effort has ever been performed in Iran. Although, the effectiveness of protected areas in biodiversity management is often debated and different studies have reported different results (e.g. Rodrigues et al., 2004; Catullo et al., 2008), but there was no research to evaluate this factor for important taxonomic groups such as mammal species.

The results showed that environmental variables may have no significant effect on mammal species distribution, though some parameters determine the distribution of these species. According to attained results, slope, NDVI and annual precipitation were the most important variables that had influence on mammal species distribution in Iran. These findings are similar to the results of other studies in Iran (Makki et al., 2013; Bashari and Hemami, 2013). They found out that food availability and topography of the area were the main variables that determine the habitat suitability for *Ovis orientalis*. Mohammadi et al. (2015) illustrated that NDVI is one of the most important variables to show the habitat suitability of *Dama dama mesopotamicus*. However, slope and NDVI are not restricting factors for distribution of *Panthera pardus* (Erfanian et al., 2013). The effective variables for species distribution are not similar in different species. Therefore, in this study the difference between species has been considered. Small Variances for first three variables means they are extremely important for numerous species. However, some variables such as elevation above the sea level had a high variance (Fig. 3).

A considerable part of Iran (more than 20 percent) is defined as suitable habitats for species like *Ovis orientalis. Capra aegagrus* suitable habitats have around 60 percent overlaps with protected area (Table 1). Therefore, it's obvious that the notable parts of habitats for big mammal species were located inside the protected area. Bashari and Hemami (2013) also confirmed the importance of protected areas in conserving *Ovis orientalis* populations in Iran. Karami et al. (2015) demonstrated that big mammal species are rarely seen outside of protected areas in Iran. Conversely, Swanepoel et al. (2013) showed that most suitable habitats for leopard occurred outside of protected areas in South Africa. However, this situation for some species is very critical, for instance, around five percent of the country was defined as suitable for *Ursus thibetanus* and just less than five percent of this area was located inside the protected area. In other words, there are big gaps between suitable habitats and protected areas for some mammal species in Iran.

Forecasting biodiversity hotspots

The results illustrated that the biodiversity hotspots are mostly distributed in north and west of Iran along the Alborz and Zagros mountain range (Fig. 1). These results are in line with Mittermeier et al. (2011) and Myers et al. (2000) studies that introduced north and west of Iran as part of the Irano-Anatolian biodiversity hotspots, the so-called 20th global hotspot region. These mountains ranges are also characterized by high levels of plant endemism even higher than temperate European mountain ranges such as the Alps (Tribsch and Schönswetter, 2003; Noroozi et al., 2008). Most likely, several factors contribute in promotion of endemism. During the late Pleistocene glaciations, as the snowline descended in SW Asia, wide altitudinal ranges of Alborz and Zagros mountain range were emerged from ice. As a result the Irano-Turanian high altitude plant species were downward-migrating (Djamali et al., 2012). In addition, the Alborz mountain range appears to be rather isolated from the Zagros mountain range by arid lowlands. These effective dispersal barriers caused the escalation in richness of the range-restricted plant species (Noroozi et al., 2016).

The results showed that approximately 27% of Iran is potentially suitable to announce as biodiversity hotspots, but these areas are severely fragmented. The suggestion is to consider dispersal corridors for facilitating the movement of animals among habitat fragments. Connectivity is fundamental to guarantee conservation, dispersal and viability of animal population (Cushman et al., 2013; Roscioni et al., 2014; Saura et al., 2014) and our results could be the basis for implementing further research that would take into account even connecting corridors among habitat fragments and protected areas. Almost 57% of hotspots were located in protected areas. Therefore, all the efforts for protecting biodiversity hotspots should firstly focus on areas which are not currently under protection of conservation laws. Also, it is essential to pay more attention to selection complementary protected areas within biodiversity hotspots, and to promote a network function of protected areas within these hotspots in Iran. Although the percentage of Iran's protected areas is significant (around 10 percent), it is still below the world average (15.5 percent) and short of the Aichi targets adopted by the UN Convention on Biological Diversity to protect 17 percent of the world's terrestrial and inland water areas by 2020 (Jowkar et al., 2016).

Appendix A.

See Figs. A1–A11.

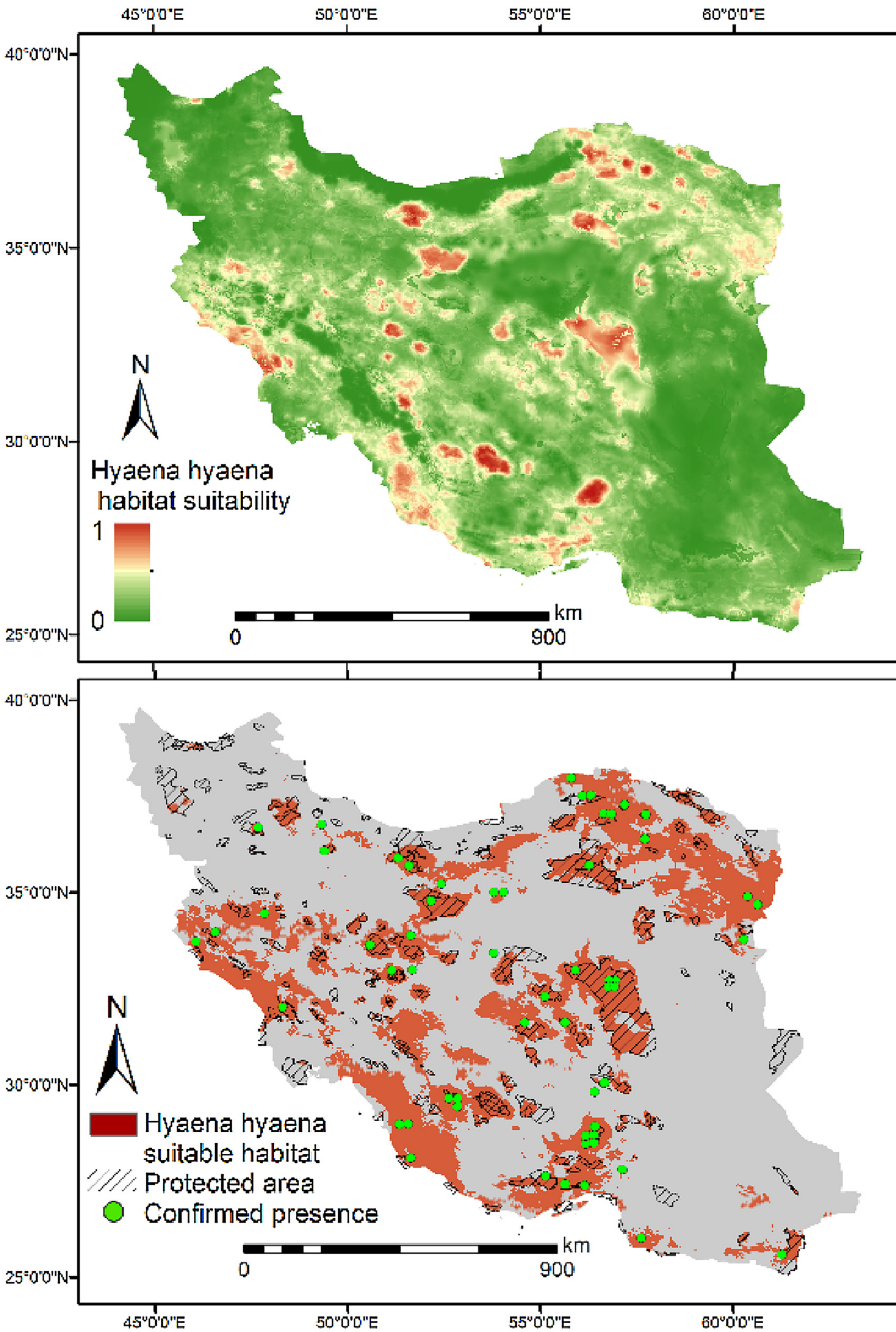

Fig. A1. Habitat suitability of *Hyaena hyaena* in Iran and gaps between suitable habitats and protected areas.

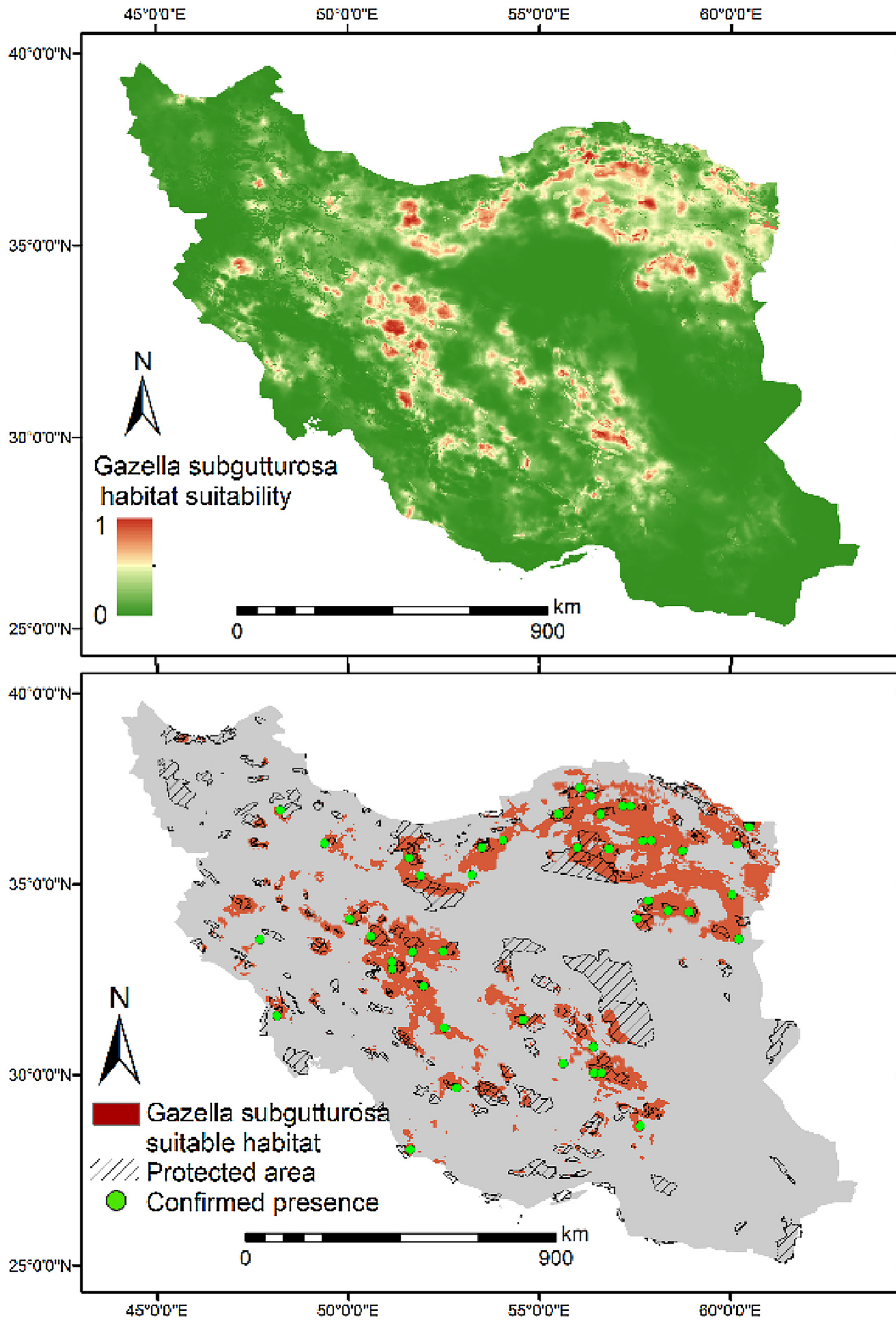

Fig. A2. Habitat suitability of *Gazella Subgutturosa* in Iran and gaps between suitable habitats and protected areas.

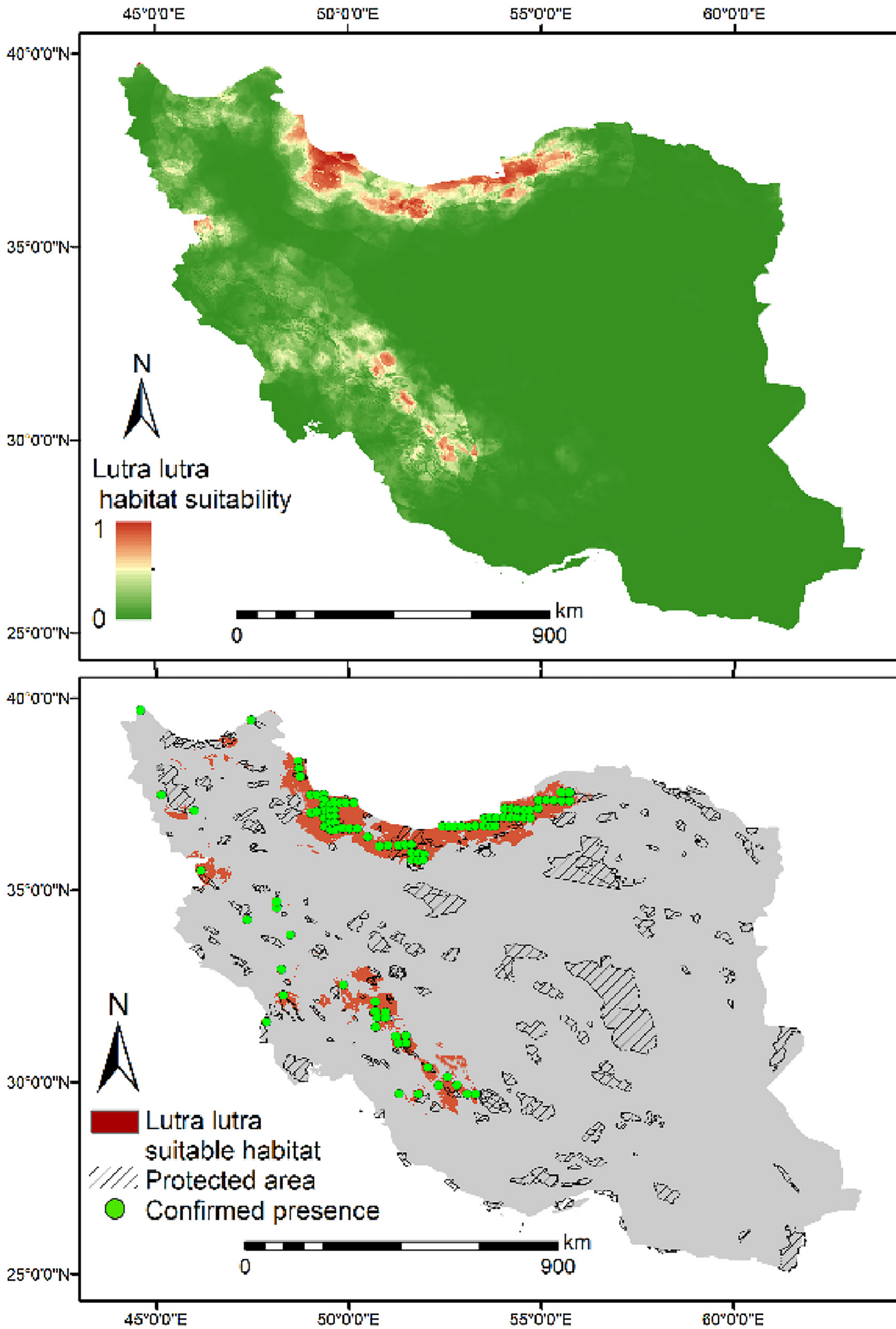

Fig. A3. Habitat suitability of *Lutra lutra* in Iran and gaps between suitable habitats and protected areas.

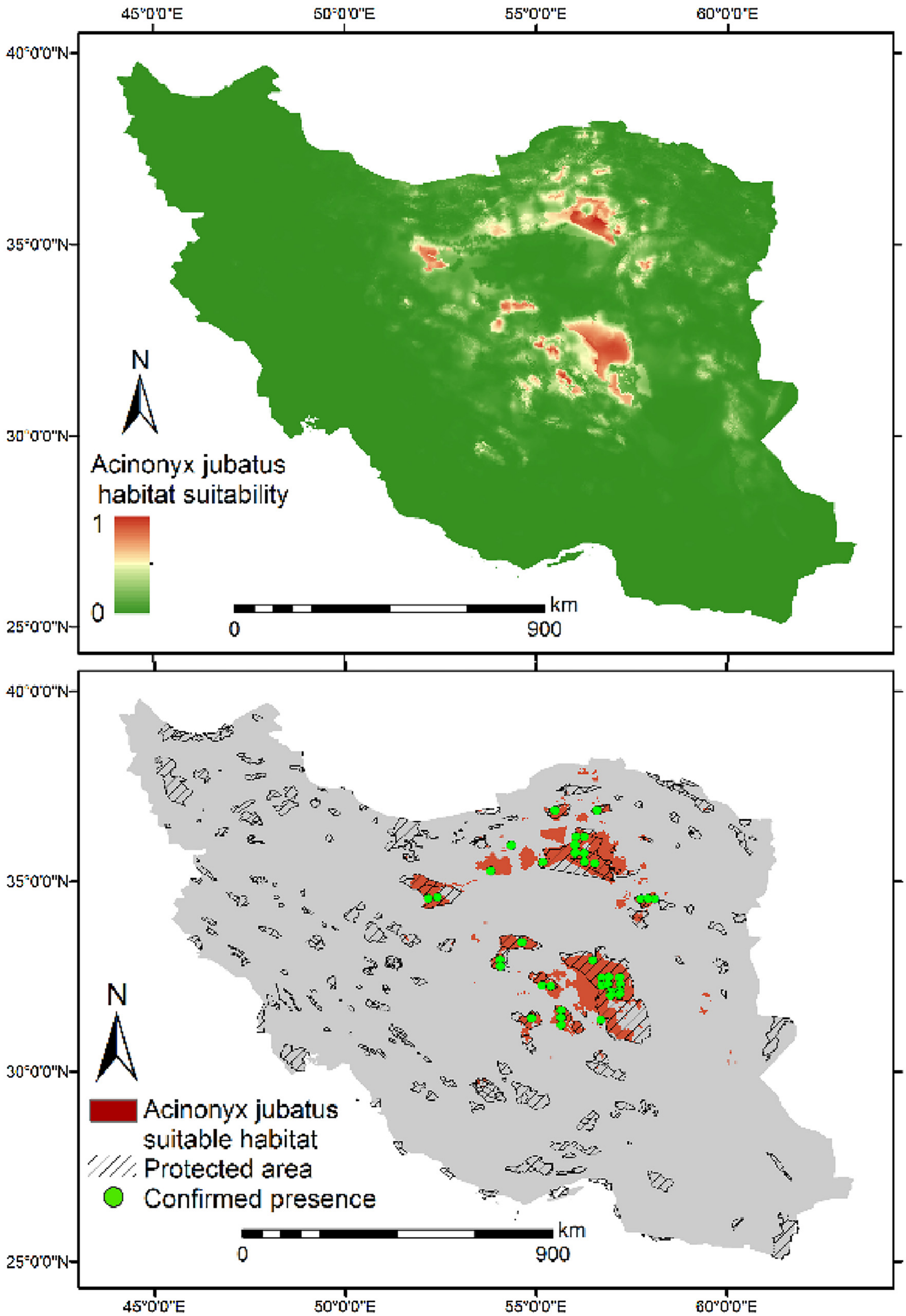

Fig. A4. Habitat suitability of *Acinonyx jubatus* in Iran and gaps between suitable habitats and protected areas.

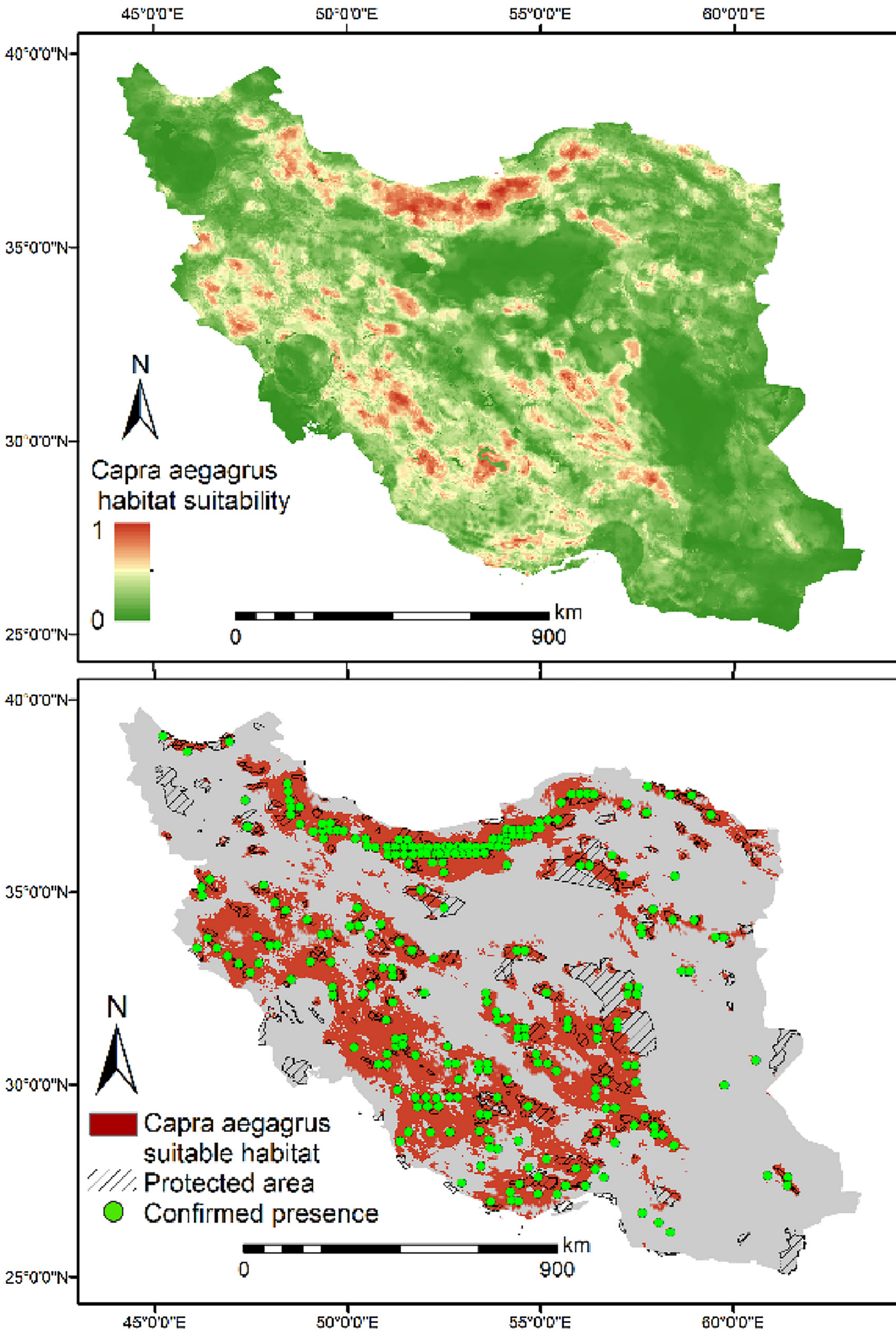

Fig. A5. Habitat suitability of *Capra aegagrus* in Iran and gaps between suitable habitats and protected areas.

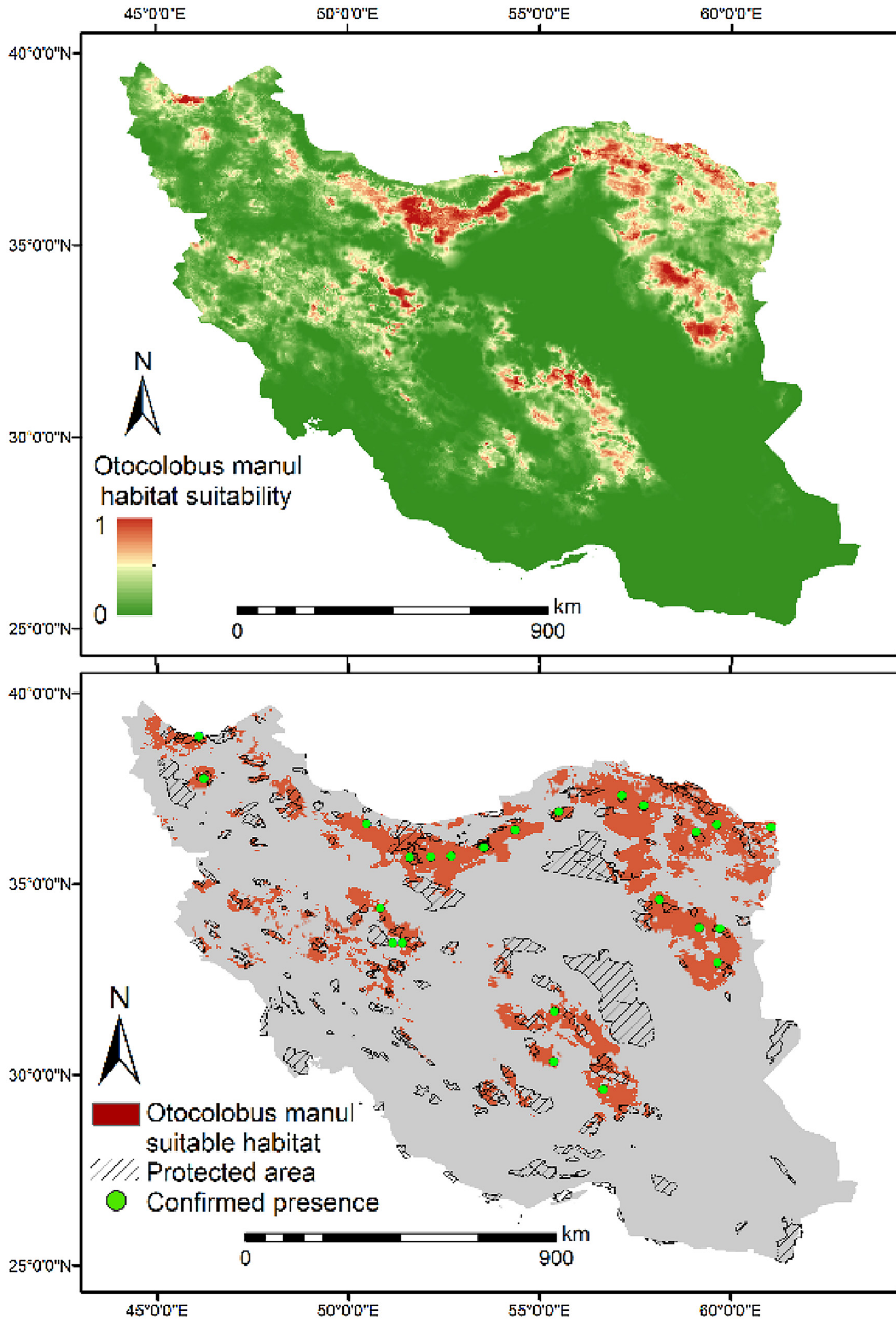

Fig. A6. Habitat suitability of *Otocolobus manul* in Iran and gaps between suitable habitats and protected areas.

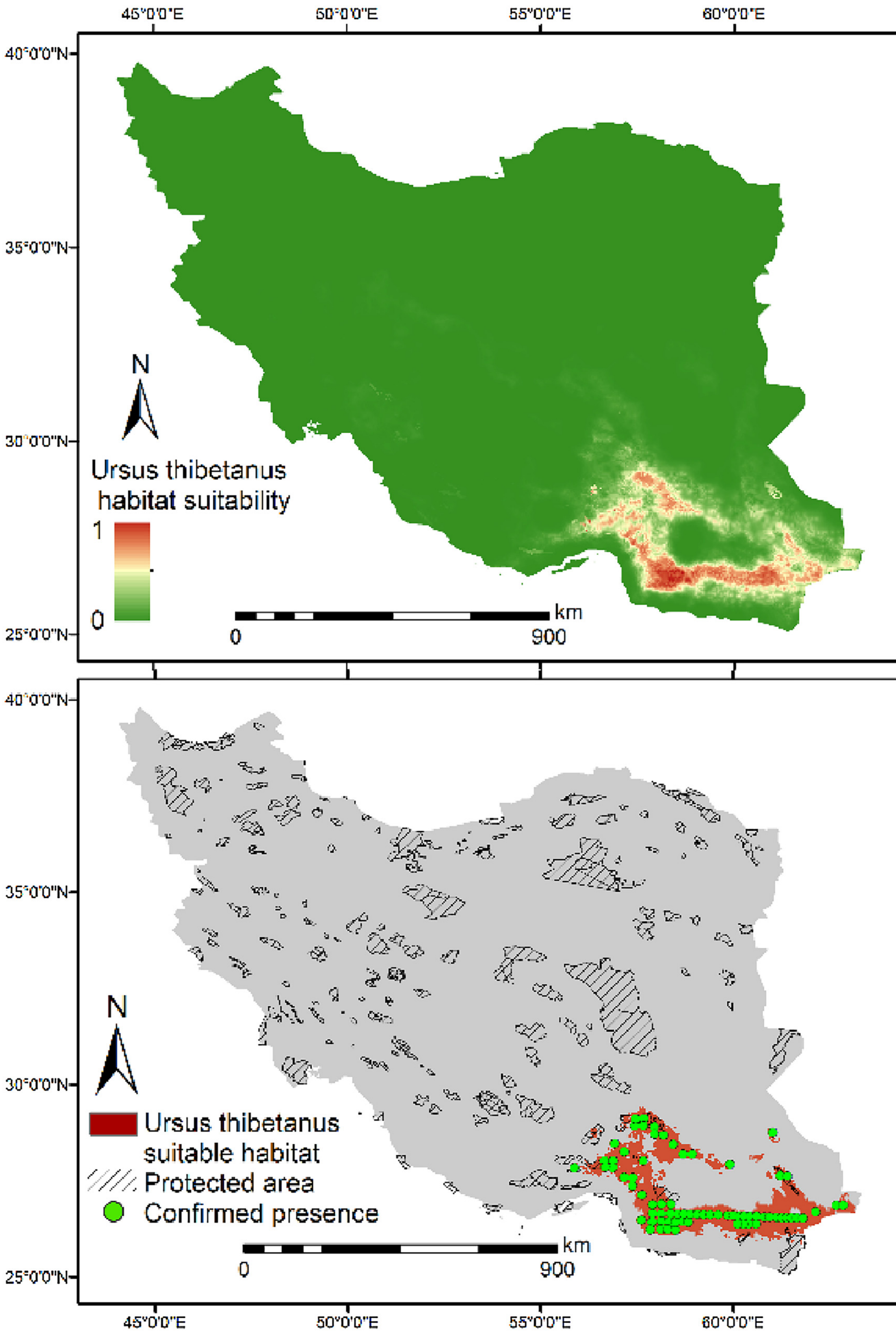

Fig. A7. Habitat suitability of *Ursus thibetanus* in Iran and gaps between suitable habitats and protected areas.

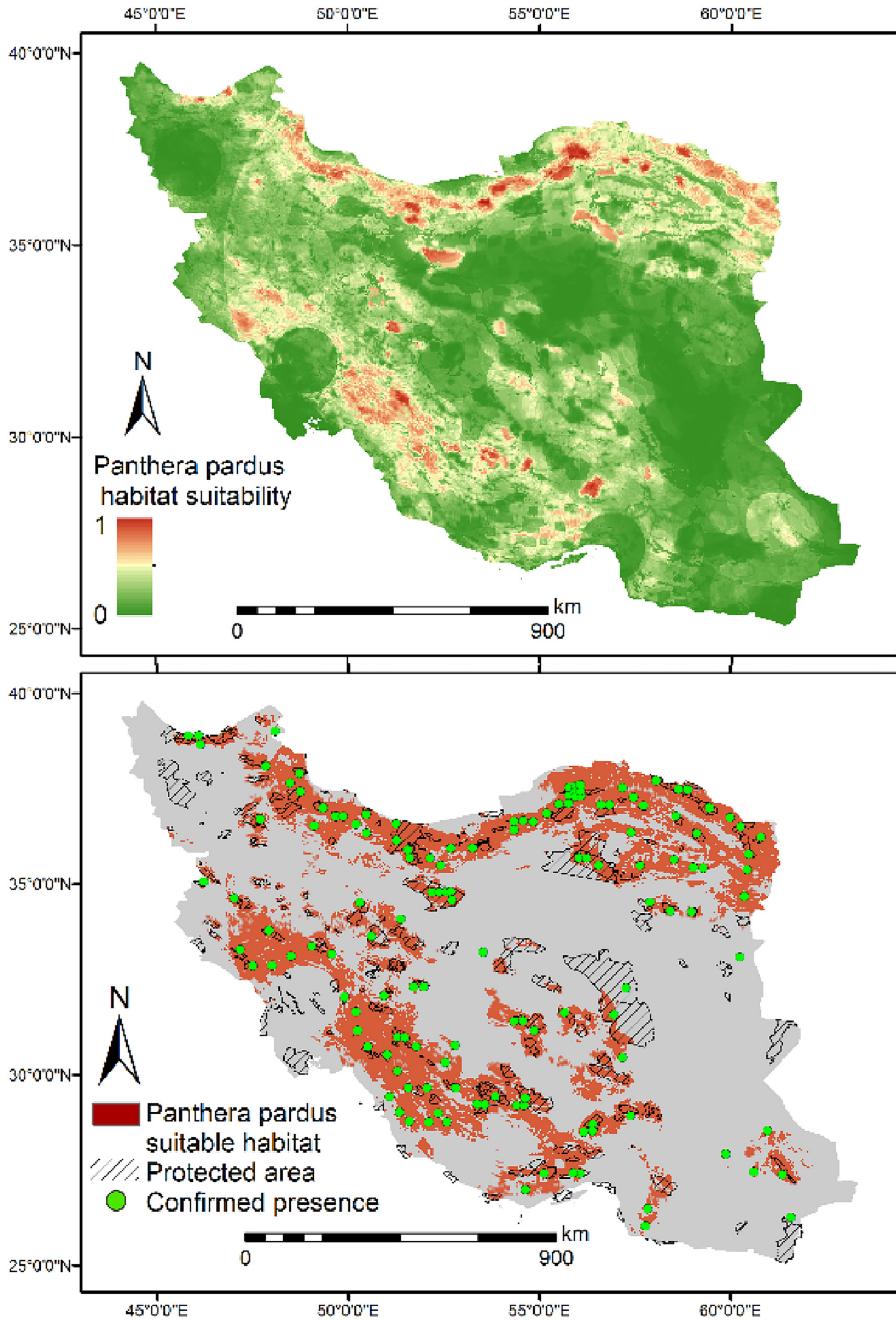

Fig. A8. Habitat suitability of *Panthera Pardus* in Iran and gaps between suitable habitats and protected areas.

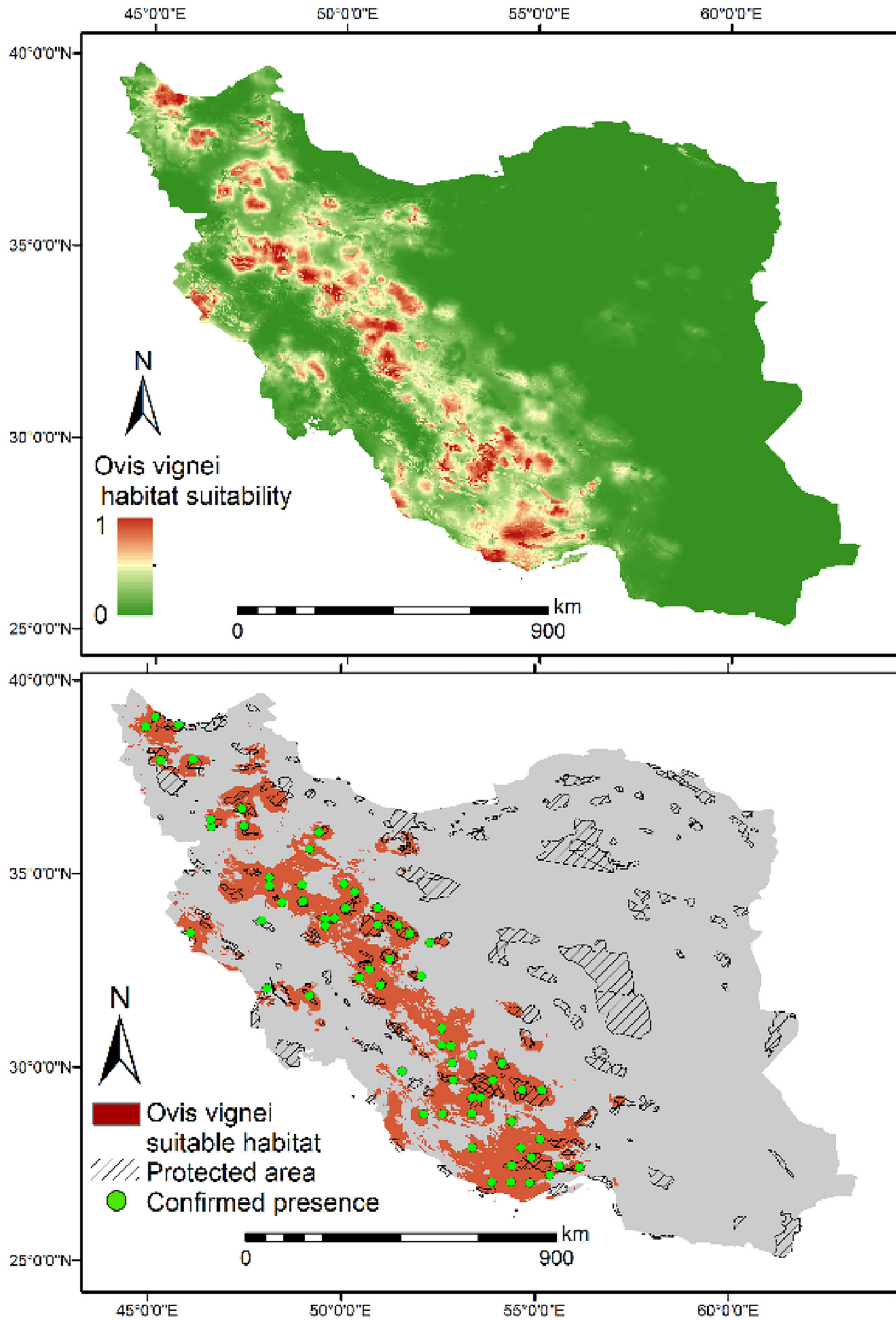

Fig. A9. Habitat suitability of *Ovis Vignei* in Iran and gaps between suitable habitats and protected areas.

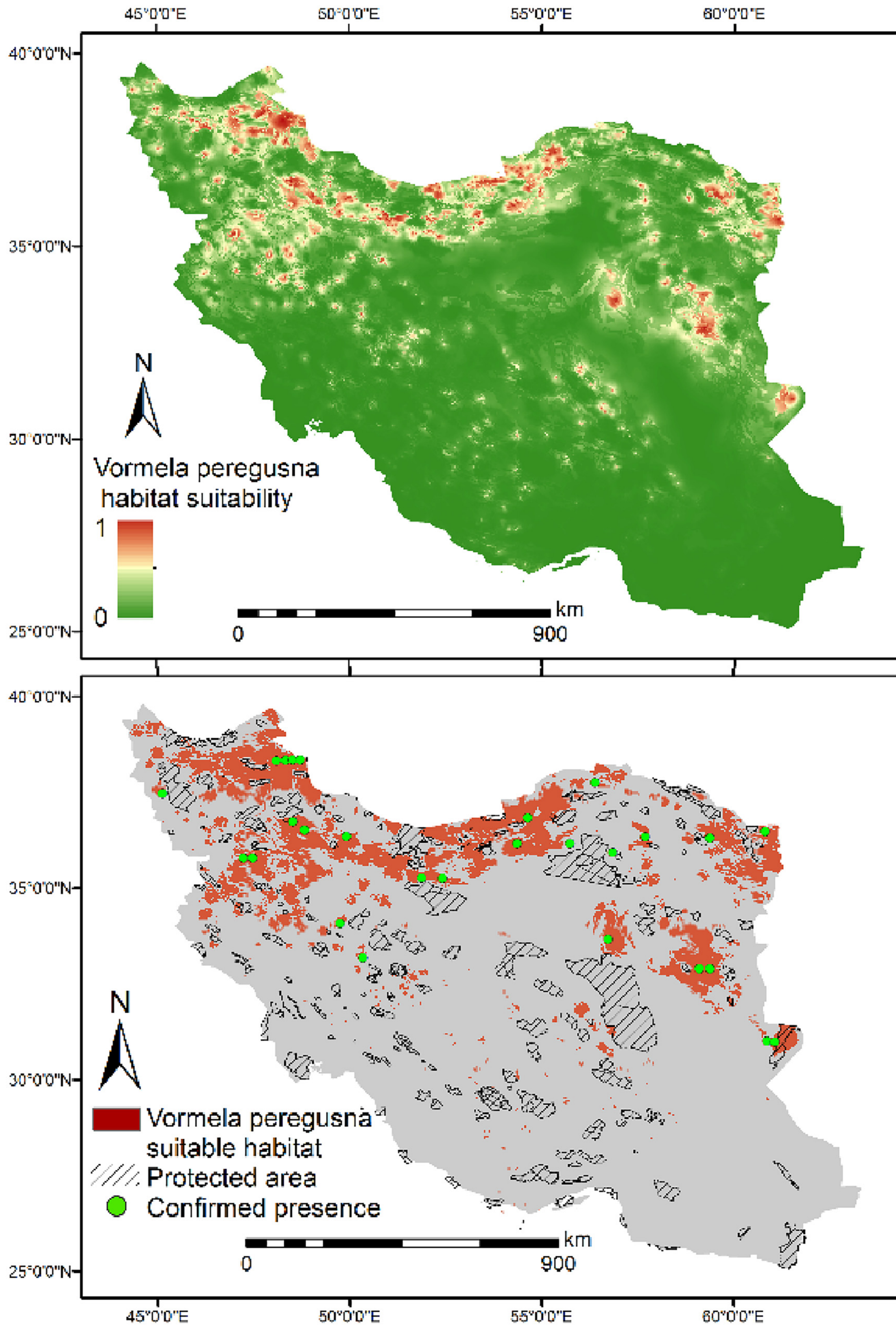

Fig. A10. Habitat suitability of *Vormela peregusna* in Iran and gaps between suitable habitats and protected areas.

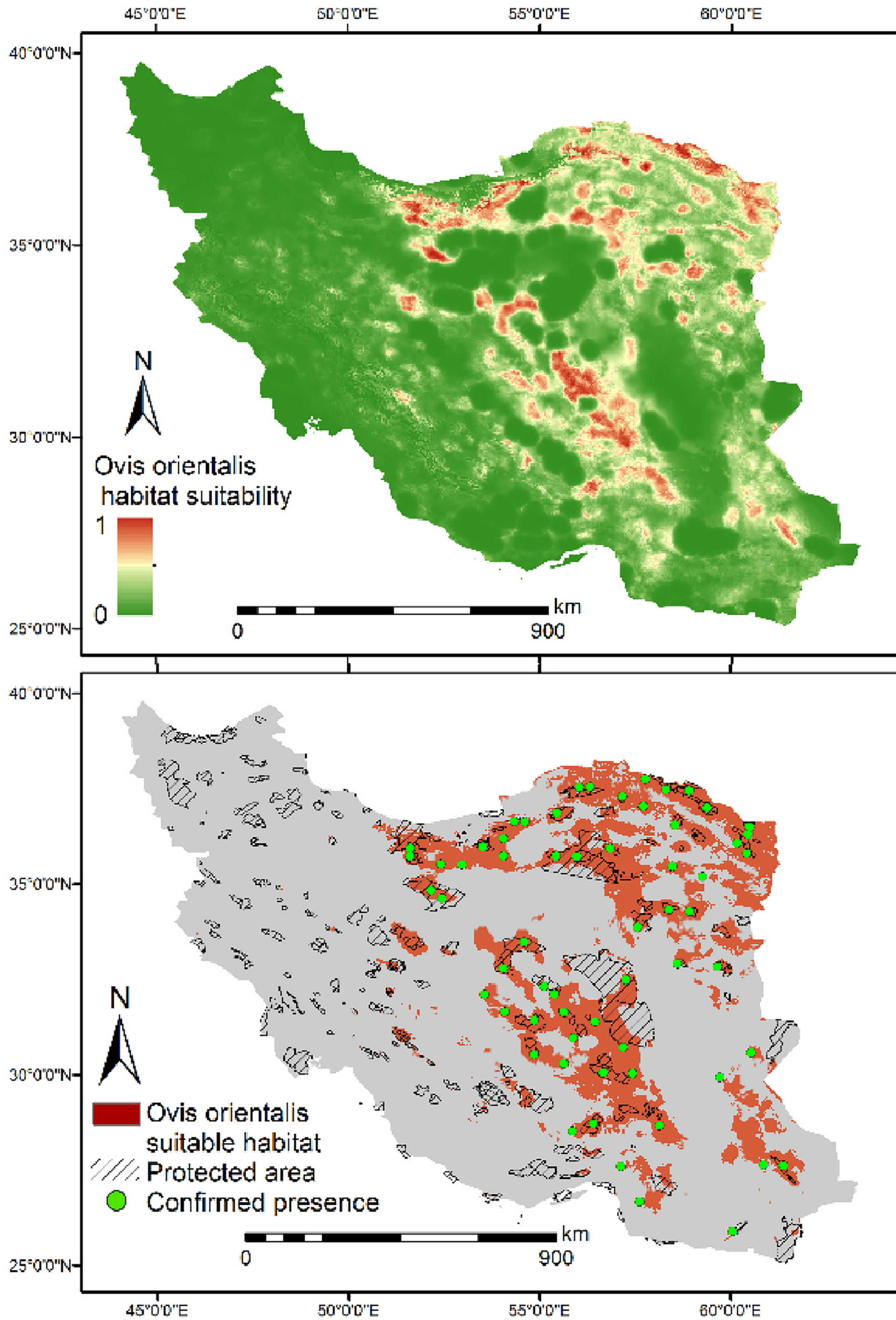

Fig. A11. Habitat suitability of *Ovis orientalis* in Iran and gaps between suitable habitats and protected areas.

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