Landscape Ecology

SPECIES AND SPACE: a combined Gap analysis to guide management planning of conservation areas

--Manuscript Draft--

Manuscript Number:	LAND-D-20-00009R1
Full Title:	SPECIES AND SPACE: a combined Gap analysis to guide management planning of conservation areas
Article Type:	Original research
Keywords:	conservation area, species distribution models, graph theory, connectivity, large carnivores, conservation planning
Corresponding Author:	Mohsen Ahmadi, Ph.D. Isfahan University of Technology Isfahan, Isfahan IRAN, ISLAMIC REPUBLIC OF
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Isfahan University of Technology
Corresponding Author's Secondary Institution:	
First Author:	Mohsen Ahmadi
First Author Secondary Information:	
Order of Authors:	Mohsen Ahmadi
	Mohammad S. Farhadinia
	Samuel A. Cushman
	Mahmoud-Reza Hemami
	Bagher Nezami Balouchi
	Houman Jowkar
	David W. Macdonald
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Context With accelerating global declines in biodiversity, establishment and expansion of conservation areas (CAs) have increasingly been advocated in recent decades. Gap analysis has been useful to evaluate the sufficiency and performance of CAs. Objectives Researchers often identify putative gaps in the protection of biodiversity in CA networks, drawing on evidence from species occurrence patterns (i.e., representation), yet the effect on the gap analyses of the spatial configuration of CAs is poorly understood. Methods Focusing on two large, charismatic carnivores of western Asia, Persian leopard and Asiatic cheetah, we used species distribution models (SDMs) to map potentially suitable habitats throughout the region. We calculated species representation for four categories of CAs within the conservation network in Iran and used a new application of graph theory to include their spatial configuration into our gap analysis. We then regressed species representation against spatial configuration to provide more insights into the performance of different categories of CAs. Results Results showed that the existing CA network conserves only 32% of the suitable habitats for the two species. Leveraging spatial configuration of the conservation areas into the gap analysis, however, revealed that the recently-established less strictly CAs disproportionately provide a higher contribution to the collective effectiveness of the entire conservation network. Conclusions We introduce network bias as a new concept in reserve design and argue that incorporating spatial configuration into CA gap analysis improves the ability

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

	to evaluate the effectiveness of reserve network designs, and is an important decision support tool for integrated conservation planning.
Response to Reviewers:	Reviewer 1: Overall, it is a nicely written paper, which investigate the distribution range of two species of conservation importance in Iran and also the importance of existing conservation areas in providing structural connectivity among the species' core habitats. I have a few major concerns with the analysis used in the methods that authors should address before the manuscript being accepted. *Response: We are glad the reviewer thought the paper addressed an important and novel topic and appreciate the positive feedback on its overall presentation. Keywords The list of keywords is not fit to the paper and aims. Please re-write the keywords based on the aims and findings. Also write "species distribution models" instead of SDM. *Response: Done. We changed the keywords and wrote species distribution models instead of SDM. It is worth mentioning that we tried to not use keywords from the title of the manuscript. L28: As you know, PAs in Iran are classified into five main groups (i.e. national parks, wildlife refuges, protected areas, natural monuments, and no-hunting area). One of these classes are protected areas. So, I thinks that authors use a better title for overall term such as conservation areas or conservation reserves throughout the text instead of PAs. In line 82, you have used "Iranian Conservation Network; ICN" that is a better title than PAs. *Response: Done. We used conservation areas throughout the text instead of PAs. Introduction In the introduction section, authors should highlight the importance of gap analysis in evaluating the importance of conservation areas and establishing new conservation area by providing a comprehensive literature review. In the introduction I miss a proper literature review. How species distribution models (SDMs) and gap analysis can help to inform conservation efforts aimed at establishing new conservation area?. *Response: We appreciate the reviewer for this helpful suggestion. We added more detail on the importance of gap analysis and extended our literature review. Please see paragraphs 1 and 3 of the revised manuscript. L64: Please use the full name of CA in first mention and then its abbreviation throughout text *Response: Done. L73: "rock and ice area"! needs a reference *Response: We added the reference to the term. L90: The authors should provide the authorship for taxa at the first time that they appear in the text. *Response: We mentioned the authorship for the species for the first time. L92: needs reference *Response: We added relevant references to the sentence. L97-105: in this paragraph authors provide details about the methodological that are appropriate for method section. Please trim the paragraph and provide more details in methods. For example I think that there is no need to add the name of landscape connectivity metric used for assessing structural connectivity among PAs (i.e. probability of connectivity; PC) instead of, author can write " we used landscape connectivity metrics to …..". *Response: We appreciate the reviewer for this suggestion. We used “landscape connectivity metrics” instead of “probability of connectivity (PC) index”. Methods Study area and species data In the study area, I miss a proper description of the target species. That data is very relevant and should be an important part of the study area. Why these species are

important to assess? Where are the species found? The density of each of the species? A longer description of the study areas is needed including describing the protected areas and the species present etc. The reader needs more info to be able to follow the results.
*Response: We thank the reviewer for this suggestion. Generally, the description of the species has been widely reported in many other relevant studies. In this paper, we used these two species as a model to evaluate gap analysis of conservation areas and we focused more on the importance of conservation coverage and spatial configuration of protected areas. In this kind of study, a detailed description of the species does not necessarily add utility and can distract from the main objective. More importantly, due to the world limitations and to prevent the elongation of the article we decided against adding more details about the species. But we respect the recommendation of the reviewer and added a longer description of the study areas including a description of the conservation areas.

L117: Although spatial filtering of occurrence data can help reduce sampling bias, it isn't always the only solution required. This subsampling reduces the spatial aggregation of records but does not correct the lack of data due to low sampling effort in some areas'. Please review the other approaches for correcting sampling bias (e.g. using information on sampling effort or a target background approach)? These should be mentioned in the discussion section.
*Response: We agree with the reviewer that there always might be some levels of sampling bias and spatial bias in occurrence points. We have added more detail on our procedure to deal with probable bias in our dataset. We have re-phrased the section on the Study area and Species data in the Methods and clarified the procedure. As you mentioned, spatial bias in presence records needs to be accounted in the modeling approach. Yet, and please forgive the forthcoming long development, the issue is a source of controversy. Spatial bias results from how occurrence points have been gathered from field sampling or available data resources of the target species. Generally, two methods have been recommended to account for this inefficiency; (1) spatial filtering and; (2) target-group background (i.e. background manipulation). As proposed by Phillips et al. (2009) and Elith et al. (2010), background manipulation through selecting a biased background point corresponding to clumped presence points improves the average performance of modeling methods. Particularly Elith et al.'s article highlights the advantage of this method when the objective is projection to a novel environment, for example in the case of invasive species or future climate change. But a recently published article on the importance of correcting for sampling bias (Kramer-Schadt et al., 2013) has demonstrated that if many occurrence records are available, then spatial filtering is preferred over background manipulation. This article highlighted that while background manipulations might decrease the risk of omission errors for range-restricted species occupying a narrow ecological niche, they increase this error for the continuous species with a generalist wide-range distribution, such as the Persian leopard and/or the Asiatic cheetah. However, we draw the reviewer's attention to the fact that the occurrence points of the species were collected during a long-term field sampling by experts of these species. We believe that our dataset comes from the most comprehensive field sampling of the species and all the possible habitats for the species have been covered in our dataset. Accordingly, the existence of an imbalanced sampling effort in our data is unlikely.

L118: why did you use this threshold for filtering the occurrence data? And do you mean 5-km or 5 x 5-km? Five km distance threshold seems too small. Needs reference.
*Response: There is no rule of thumb for this threshold. We couldn't use data of the species home range or range activity since they are continuous with extensive movement abilities. Nor we could use Moran's variogram because we would lose many of the occurrence points –based on Moran's variogram at the distance of 19-km spatial distribution of occurrence points will be at random. More importantly, we didn't want to lose a lot of points since we believe that our collected data of species presence could properly reflect the spatial ecology of the species. Based on the previous studies (Farhadinia et al, 2015; Ahmadi et al., 2017) we removed repeated points within a 5-km radius to make sure that we wouldn't lose a large number of points, and at the same time, reduce the negative impacts of spatial autocorrelation. We added references to this threshold.

L119: Not enough information is provided on the presence points. Please provide a table containing the number of data for each species, the number of points collected using camera trapping, direct observation, sings, and etc.. That data is very relevant and should be an included into the supplementary file.
*Response: We added a table showing a detail of the presence points.

L125: Add the year of the reference (I,e, IFRW)
*Response: Done.

L126: Why this size? Please justify
*Response: The 5 × 5 km grid cell is, in fact, a moving window by which using neighborhood analysis we generated our variables. This method is widely used (e.g. Falcucci et al. 2013, Biological Conservation 158: 63-72 on the modeling of wolf re-colonization over the entire Alpine range, or Farhadinia et al. 2015, Biological Conservation 191: 770–778 on the distribution modelling of Persian leopard in the Iranian Caucasus).

127-133: Authors have used distribution maps of prey species as proxy for considering the effect of prey on the spatial distribution of the target species. Because in addition to habitat suitability, the abundance/density of each prey species should also be taken into account. So, do you think that your methods for considering the effects of prey species is a robust method?
*Response: We agree with the reviewer that abundance and/or density of prey species could provide valuable information to our modelling approach. However, in our study area, which extends to the whole area of Iran, detailed data on the prey species are unavailable. Therefore, for prey distribution, we used the shapefiles from the atlas of the species distribution and overlaid the distribution of main prey of the speceis. Although these atlas data are based on a 25 x 25 km grid resolution, and therefore, may appear relatively coarse, it nevertheless provides reasonably acceptable information when applied to the extent of our study area, the entirety of entire Iran. Moreover, we overlaid shapefiles of the prey and calculated distance to these areas for the entire extent of the study area, which mitigated the coarseness of this variable.

L127-129: again, provide the authorship for taxa at the first time that they appear in the text.
*Response: Done.

L128: how about wild boar (sus scrofa). Why you didn't add the distribution data for this prey species into the analysis? Please read the fowling paper
- Sharbafi, E., Farhadinia, M. S., Rezaie, H. R., & Braczkowski, A. R. (2016). Prey of the Persian leopard (Panthera pardus saxicolor) in a mixed forest-steppe landscape in northeastern Iran (Mammalia: Felidae). Zoology in the Middle East, 62(1), 1-8.
*Response: As we explained before, we used grids of prey species which have been generated for the entire extent of Iran. In this dataset, the presence of wild boar has been proved for almost all parts of the country, except for deserts and non-vegetation areas. Accordingly, there is no noteworthy spatial heterogeneity in the distribution of this species that could be valuable in our large-scale study design. Moreover, the reference that the reviewer has kindly mentioned has been implemented in a limited area with a small spatial scale. It is important that predictor variables capture the conditions on which the response variable actually depends, at the relevant spatial resolutions/heterogeneity and with uncertainty that can be quantified in the final model.

L142: The cutoff used to reduce the number of correlated predictors used is high. You should probably be more conservative. Please provide references.
*Response: This cutoff is ordinary for screening the variables for example please see Ashrafzadeh et al. 2109 or Ahmadi et al. 2017. Moreover they are relevant variables that potentially could influence the distribution of the species, hence, one of the objectives was to assess the response of the species to them.
Ashrafzadeh, M. R., Naghipour, A. A., Haidarian, M., Kusza, S., & Pilliod, D. S. (2019). Effects of climate change on habitat and connectivity for populations of a vulnerable, endemic salamander in Iran. Global Ecology and Conservation, 19, e00637.
Ahmadi, M., Nezami Balouchi, B., Jowkar, H., Hemami, M. R., Fadakar, D., Malakouti-Khah, S., & Ostrowski, S. (2017). Combining landscape suitability and habitat

connectivity to conserve the last surviving population of cheetah in Asia. Diversity and Distributions, 23(6), 592-603.

L150: Why did you use these number of backgrounds?. For machine-learning techniques (such as MaxEnt), the number of background localities had more impact on model accuracy than the selection method and averaging several runs with fewer pseudo-absences yield the most predictive models. Therefore, using fewer background points and the same number of background points as available presences with equal weighting for presences and absences points to run the MaxEnt models is a better choice for the studies working on rare species with few number of presence points. Please read the following papers.
- Barbet-Massin M, Jiguet F, Albert CH, Thuiller W (2012) Selecting pseudo-absences for species distribution models: how, where and how many? Methods Ecol Evol 3(2):327-338
- Radosavljevic A, Anderson RP (2014) Making better Maxent models of species distributions: complexity, overfitting and evaluation. J Biogeogr 41(4):629-643
*Response: We agree with the reviewer that selecting the number of background (pseudo-absences) points will largely affect results of an SDM analysis. However, we disagree with the arguments that severely downsampling background is an effective solution. For example, Cushman et al (2017), using machine learning to predict deforestation showed that imbalance between the true ratio of ccurrence/nonoccurrence between the training sample and the actual data strongly biases predictions. Therefore, for rare species it is very important to use a much larger sample of background both to adequately represent the true distribution of available conditions and also to provide a ratio of occurrence to nonoccurrence in the training data that do not strongly bias the predictions. In our study, we used two regression-based models (GLM and GAM), and two machine learning methods (MaxEnt and GBM). As you can see from Barbet-Massin et al. (2012) using a large number (e.g. 10,000) of pseudo-absences with equal weighting for presences and absences provides best results when using regression techniques. Using 10,000 randomly selected background points is also a recommended default measure in the MaxEnt model (Phillips et al. 2006). Although Barbet-Massin et al. (2012) recommend using the same number of pseudo-absences as available presences for machine learning methods they didn't consider MaxEnt in their analysis. More importantly, as we now species-specific tuning of model parameters (Radosavljevic and Anderson, 2014) and even the extent of the target area and raster resolution of variables (Franklin et al. 2010 and Guisan et al. 2017) are important for parameterization of any SDM analysis. We note that based on the 1-km resolution of raster layers and our large study area (1,648 k km2) we had to select a large number of background points to cover a reasonable number of pseudo-absences points for our analysis.
- Franklin J (2010) Mapping species distributions: spatial inference and prediction. - Cambridge University Press.
- Guisan, A., Thuiller, W. & Zimmermann, N. E. (2017) Habitat Suitability and Distribution Models: With Applications in R. Cambridge University Press.
- Cushman, S. A., Macdonald, E. A., Landguth, E. L., Malhi, Y., & Macdonald, D. W. (2017). Multiple-scale prediction of forest loss risk across Borneo. Landscape ecology, 32(8), 1581-1598.

L156: Why did you use 10th percentile of suitability score at the occurrence points to classify continues suitability maps? As you know the extent of suitable core habitats depends on the thresholds used for classification. So justify the selected threshold by adding reference or doing a sensitivity analysis.
*Response: 10th percentile of suitability score is a common suitability threshold that has also been provided in suitability thresholds of MaxEnt software. Moreover, Guisan et al. 2017 also mentioned it as a commonly-used threshold.
- Guisan, A., Thuiller, W. & Zimmermann, N. E. (2017) Habitat Suitability and Distribution Models: With Applications in R. Cambridge University Press.

L161-168: please provide more information about the software used for trimming the core habitat patches? Which software did you use for that? GUIDOS? If yes, please add the name and reference to it.
*Response: We did this analysis in the ArcGIS software and we didn't use any specific software for doing them.

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

L184-204: Authors have provided more details on the connectivity measure used for connectivity analysis. This paragraph can be shortened. I suggest trimming these lines and add reference to provide more details for readers. or, this details can be moved into supplementary files.
*Response: Done. We shortened this section and moved the details to the Supplementary Information.

L194: why did you use these thresholds? As you have mentioned earlier, the longest movement that has been recorded for Asiatic cheetah in arid ecosystems of Iran is 200-km. so I think that authors should test longer dispersal distances. Please read the following paper.
- Khosravi, R., Hemami, M. R., & Cushman, S. A. (2018). Multispecies assessment of core areas and connectivity of desert carnivores in central Iran. Diversity and Distributions, 24(2), 193-207.
*Response: Indeed we used 200-km as the maximum dispersal distance for calculating dPC index. Here a typo error has occurred and we mistakenly mentioned 150-km. Through the manuscript and as you can see in Figure 2 and 3 we indicated that we used 200-km as the maximum dispersal distance for dPC index.

L200: As you are targeting to evaluate the importance conservation areas for structural connectivity, I would recommend to include and separately assess the three fractions of the dPC metric (intra, flux and connector), rather than only the total dPC values. These individual fractions allow you to provide a more comprehensive and potentially informative picture on the importance of each conservation area.
*Response: We thank the reviewer for this helpful recommendation. We have now added a new table containing three fractions of the dPC index (dPC-intra, dPC-flux and dPC-connector) for each of the conservation units.

Results
L207-208: This sentence is more appropriate for methods not results. Move to methods or delete.
*Response: Done. We deleted the sentence.

Discussion
The discussion section is too long and can be shortened. Please just try to focus on interpretation of main results in the discussion. Authors have mentioned to the importance of no-hunting areas in facilitating species movements. The importance of this category of conservation areas, as stepping stone, also the importance of rugged landscapes and prey availability in providing suitable habitats for the study species has been previously noted (e.g. Khosravi et al., 2018; Khosravi et al., 2019). Please do more literature review and compare you results to other previous works. Finally, as the authors investigated the importance of existing conservation areas only based on the distribution amp of two species (cheetah and leopard), so you should interpret the obtained results more cautiously.
- Khosravi, R., Hemami, M. R., & Cushman, S. A. (2018). Multispecies assessment of core areas and connectivity of desert carnivores in central Iran. Diversity and Distributions, 24(2), 193-207.
- Khosravi, R., Hemami, M. R., & Cushman, S. A. (2019). Multi-scale niche modeling of three sympatric felids of conservation importance in central Iran. Landscape Ecology, 34(10), 2451-2467.
*Response: Done. We thank the reviewer for these comments on the Discussion. As we did the analysis based on both SDM and gap analysis, we had to discuss results obtained from both of them. We tried not to stretch the Discussion. For example, we summarized the patterns of the species habitat preference to only one paragraph at the end of the Discussion. We also did more literature review and added the reference that the reviewer has kindly suggested.

We thank reviewer 1 for the positive criticisms and comments to improve the quality of our manuscript.

Reviewer 2:
Overall I really enjoyed reading your paper. I thought your species choice was great,

using two charismatic species with different habitat requirements and degrees of human tolerance was a good way to illustrate your example. Your analysis and methods have merit and the topic of protected areas if very timely, as you are surely aware.

The biggest issue to me was clarity. I found it hard to keep track of what was a PA vs. a CA, what level of protection was afforded, etc. I would appreciate if you could clarify some of these things throughout the manuscript. When in doubt, be explicit, and define your terms at the outset. I have outlined some specific concerns below.
*Response: To avoid ambiguity we used conservation areas throughout the text instead of PAs.

Line 2: I'm a bit confused about the title. Since your manuscript is largely focused on the spatial configuration of protected areas, I feel like the word configuration is worth mentioning here. Space does not necessarily equate with configuration in my mind. It also seems like it should be species AND space/configuration, not one or the other.
*Response: we used species as a term of species representation and space as a term of spatial configuration. We believe that the combination of “SPECIES and SPACE” is an absorptive title for the readers. However we agree with the reviewer and changed OR to AND.

Line 44: Similar to my concerns with the title, I'm not certain that the term "spatial bias" that you introduce here is appropriate. Spatial bias already has certain connotations and doesn't necessarily mean configuration. I think something like configuration bias, network bias, or connectivity bias would be better.
*Response: We appreciate the reviewer’s suggestion and used network bias instead of spatial bias.

Line 67: Typo
*Response: Done. The typo error was fixed.

Line 224, 230-234: WR, NHA and NP are never defined in the body of the text, only in the figure titles. Overall, it felt like excessive use of acronyms in general, and I had to keep looking up what they were all referring to. I would strongly prefer that some of these be spelled out, as it will really help the readability of your manuscript.
*Response: Now in the new version of the manuscript we added more description on the definition of the conservation areas. Please see the first paragraph of the Study area. We also spelled out some of the abbreviations, spatially those in the Discussion.

Line 246: Not sure what is meant by "apparent on a global scale". Do you mean that these biases are not limited to your study area? Please clarify.
*Response: Done. Yes, we mean that those biases in Iran’s conservation network are also apparent on a global scale. We added the word ‘also’ to denote this.

Line 251: This is the first mention of Natural Heritage Sites? I'm confused about how these categories match up with those in the table and throughout the manuscript.
*Response: Natural Heritage Site corresponds with the Category III of IUCN categories of protected areas. These sites are just natural monuments that don’t provide any specific area for which conservation attempts would be implemented.

Line 304: I don't think "over-all property" makes sense here… you could probably just cut that out: "connectivity varies subject to the attributes of the target…"
*Response: Done. We removed the unclear part.

Line 320: typo
*Response: Done. The typo error was fixed.

Table 1: Can you put more detail into the title of this? The table should be able to stand alone, and I found myself referencing back to the text in order to figure out what was going on, even though it is quite straight forward. Explicitly stating what is meant by conservation coverage and conservation efficiency would help, and having this explicitly covered in the body of the manuscript would be nice as well. Also, do these line up with IUCN protection categories? If so, it would be interesting to include the respective categories in the table to provide some global context to the level of

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

	protection afforded, even if it's just approximate. *Response: Done. We added more details to the caption of Table 1. In the new version of the manuscript, we extended the definition, function, and objectives of Iranian conservation areas. Please see the Study area of the Method. We also have explicitly stated the definition of conservation coverage and conservation efficiency in the main text, for this please see the first paragraph of subsection ‘Gap analysis and conservation prioritization’. We also have indicated the corresponding IUCN categories for Iran’s conservation units in the table. Figure 1: I'm not really sure what's going on with the organization of this figure. The letters seem to read clockwise? I've never seen that before. C and D should be switched? *Response: We thank the reviewer for notifying this. We reordered the letters of C and D ***We thank reviewer 2 for the positive criticisms and comments to improve the quality of our manuscript.***

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

Manuscript

Click here to access/download;Manuscript;GapAnalysis_LandscapeEcol_R1.d

Click here to view linked References

Title:

SPECIES AND SPACE: a combined Gap analysis to guide management planning of conservation areas

Authors:

Mohsen Ahmadi[1,2]*, Mohammad S. Farhadinia[3], Samuel A. Cushman[4,5], Mahmoud-Reza Hemami[1], Bagher Nezami Balouchi[6], Houman Jowkar[7], David W. Macdonald[4]

Affiliations and addresses:

[1] *Department of Natural Resources, Isfahan University of Technology, 8415683111 Isfahan, Iran. ORCID: https://orcid.org/0000-0002-9657-699X*

[2] *Swiss Federal Research Institute WSL, Dynamic Macroecology Group, 8903 Birmensdorf, Switzerland*

[3] *Oxford Martin School and Department of Zoology, University of Oxford, 34 Broad Street, Oxford OX1 3BD, UK*

4 Wildlife Conservation Research Unit, Department of Zoology, University of Oxford, Tubney, Abingdon OX13 5QL, UK

[5] *Rocky Mountain Research Station, United States Forest Service, Flagstaff, 86004 AZ, USA*

[6] *Department of Natural Resources and Environment Sciences, University of Environment, 3174674761 Karaj, Iran*

[7] *Conservation of Asiatic Cheetah Project (CACP), I.R. Iran Department of Environment, 738314155 Teheran, Iran*

* Corresponding Authors:

Mohsen Ahmadi, Department of Natural Resources, Isfahan University of Technology, 8415683111 Isfahan, Iran. Phone number: +989104897500, Email: ahmadim.bio@gmail.com

Abstract

Context With accelerating global declines in biodiversity, establishment and expansion of conservation areas (CAs) have increasingly been advocated in recent decades. Gap analysis has been useful to evaluate the sufficiency and performance of CAs.

Objectives Researchers often identify putative gaps in the protection of biodiversity in CA networks, drawing on evidence from species occurrence patterns (i.e., representation), yet the effect on the gap analyses of the spatial configuration of CAs is poorly understood.

Methods Focusing on two large, charismatic carnivores of western Asia, Persian leopard and Asiatic cheetah, we used species distribution models (SDMs) to map potentially suitable habitats throughout the region. We calculated species representation for four categories of CAs within the conservation network in Iran and used a new application of graph theory to include their spatial configuration into our gap analysis. We then regressed species representation against spatial configuration to provide more insights into the performance of different categories of CAs.

Results Results showed that the existing CA network conserves only 32% of the suitable habitats for the two species. Leveraging spatial configuration of the conservation areas into the gap analysis, however, revealed that the recently-established less strictly CAs disproportionately provide a higher contribution to the collective effectiveness of the entire conservation network.

Conclusions We introduce *network bias* as a new concept in reserve design and argue that incorporating spatial configuration into CA gap analysis improves the ability to evaluate the effectiveness of reserve network designs, and is an important decision support tool for integrated conservation planning.

Keywords: conservation network, species distribution models, graph theory, connectivity, large carnivores, conservation planning.

Introduction

Conservation areas (CAs) are critical to sustaining natural ecosystems in the context of expanding human impact. Although covering only 15% of Earth's terrestrial area (Juffe-Bignoli et al. 2014; Visconti et al. 2019), the global conservation network has been rapidly expanded in the last decade (Watson et al. 2014). However, CA networks still show substantial gaps in coverage of global biodiversity (Jenkins et al. 2013). Gap analysis and conservation prioritization have been extensively applied to evaluate the sufficiency of existing conservation networks and inform decisions regarding new CA designations (Rodrigues et al. 2004b; Santini et al. 2014). The immediate goal of a gap analysis is to quantifiably assess representativeness (i.e., complementarity) of biodiversity within CAs (Rodrigues et al. 2004b). While in many cases gap analysis is used to compare across different taxa (Jenkins et al. 2013; Rodrigues et al. 2004b), in others it is used to evaluate protection efforts (Araújo et al. 2007; Rodrigues et al. 2004a).

Among the 20 Aichi targets which the global community committed to in the Convention on Biological Diversity (CBD), target 11 emphasizes expanding the current CAs to cover 17% of terrestrial ecosystems by 2020, while preserving and improving network connectivity (CBD 2010). Since then a multitude of literature has informed the ongoing expansion of CA network (Jenkins et al. 2013), while many aspects of their functionality remain disregarded (Santini et al. 2014). For example, the spatial configuration of core habitats (or CAs as the remaining strongholds) plays a key role in the persistence of a species, particularly for large carnivores (Cushman et al. 2018;

Macdonald et al. 2018). However, in many cases CAs are fragmented into small and isolated patches, which may reduce performance in securing population viability (Santini et al. 2014), Rapid ongoing human land-use changes further compound this by increasing degradation of habitats outside of CAs and increasing the isolation of CAs from each other (Cushman et al. 2017; Hearn et al. 2018; Macdonald et al. 2018). Moreover, location bias is a common type of conservation inefficiency through which the establishment of CAs is concentrated in topographically rugged landscapes, often at high elevations, away from human-dominated areas (Gaston et al. 2008; Watson et al. 2014). Those 'rock and ice' areas (Joppa and Pfaff 2009), which often have relatively low productivity and low species richness, appear to be established to minimize conflicts with human land uses, and thus, bias towards these infertile or remote areas has lessened conservation effectiveness (Venter et al. 2018).

Gap analysis has primarily been investigated in terms of species representation in CAs, which in turn, is surrogated by habitat suitability maps (Maiorano et al. 2006; Yousefi et al. 2015) or coarse-scale geographic ranges (e.g., extent of occurrence) and atlases (Araújo et al. 2007; Jenkins et al. 2015). Species distribution models (SDMs) have been an operative tool to explore the patterns of species distribution (Franklin 2010), with many applications to biodiversity conservation (see Guisan et al. 2013 for a review). SDMs, by providing spatially explicit predictions over unsampled areas, are particularly insightful for understanding large carnivores' distribution dynamics and habitat mapping, and thus have been widely used to evaluate large carnivores' habitat suitability (Ahmadi et al. 2017; Ashrafzadeh et al. 2018; Farhadinia et al. 2015).

Traditional gap analysis based on species representation usually focuses on how well CA networks overlap, or "cover" the species distributions (Jennings 2000). Landscape ecology, and the various metrics developed in it, have been frequently used to assess the spatial configuration

of CAs (Cushman et al. 2018; Meyer et al. 2015) and their connectivity (Saura et al. 2018), yet their appropriateness to gap analysis has not been critically evaluated (but see Santini et al. 2016). In the current study, we based our gap analysis on the concept of focal species (Carroll et al. 2001) to evaluate the effectiveness of, and quantify gaps in, Iran's conservation network. We focused on the distribution of Persian leopard (*Panthera pardus saxicolor*, Pocock 1927) and Asiatic cheetah (*Acinonyx jubatus venaticus,* Griffith 1821) in Iran, two conservation-dependent species with different habitat requirements.

These two charismatic big cats are the paramount representatives of remaining terrestrial habitats in western Asia (Farhadinia et al. 2017; Kiabi et al. 2002) and have been recognized as landscape species in central Iranian plateau (Khosravi and Hemami 2019). Occurring in scattered patches within semi-arid lowland areas of central and eastern Iran, a few dozen Critically Endangered Asiatic cheetahs represent the last remnants of a historical population that spanned western Asia (Farhadinia et al. 2017). In contrast, the Endangered Persian leopards inhabit rugged terrain across much of western Asia and the Caucasus (Gavashelishvili and Lukarevskiy 2008). In some arid regions of Central Iran, their distributions overlap (Hemami et al. 2018).

Here, we used SDMs to identify potentially suitable habitats for Persian leopard and Asiatic cheetah in Iran and assessed the species representation in the CA network by calculating the coverage of suitable habitats within Iran's CAs. We then used landscape connectivity metrics and leveraged the spatial configuration of CAs into our gap analysis. Our combined approach for gap analysis enabled us to evaluate the efficiency of different categories of CAs, given their conservation strictness, species representation and spatial configuration for safeguarding these two large carnivore species. This approach is potentially applicable in other species recovery planning through enhancing gap analysis efforts.

Methods

Study Area and Species Data

We confined the study to areas with the highest probability of occurrence of Persian leopard and Asiatic cheetah in Iran, covering a total area of 1.648 million km^2 of the Iranian plateau (Fig. 1). This region of western Asia is an inland great basin which is bounded by a complex of mountain chains, including the Alborz and Zagros in the north and west, and the massifs of Afghanistan and Baluchistan in the east. Natural vegetation cover of the study area is characterized by (1) Hyrcanian forests, which form an arc from the Caspian Sea and the Alborz Mountains in the North, (2) patchy forest stands and shrublands distributed across rough steppes of the Zagros Mountains in the west, and (3) flat drylands with sporadic mountainous areas covered by xerophytic taxa of *Artemisia siberi*, *Stipa* sp. and *Salsola* sp. in the center of the plateau.

Generally, four categories of CAs are designated in Iran: National Parks (NPs), National Heritage Sites (NHSs) often called National Natural Monuments, Wildlife Refuge (WRs), and Protected Area (PAs). NPs are designated to protect outstanding environmental features and high biodiversity. Accordingly, the highest protection status is afforded to these areas. WRs and PAs are established and managed because of the high diversity of species in need of protection, and thus, WRs and PAs are in the next rank of conservation attention, respectively. These areas typically experience a higher intensity of human impacts due to the lower level of protection compared to NPs (Kolahi et al. 2012). In addition to these categories, No-Hunting Areas (NHA) are the least strictly protected category of Iranian conservation areas, where the main objective is to empower anti-poaching measures. CAs of Iran correspond with Category II, Category III, Category IV and Category IV-VI of the IUCN.

141 Species occurrence data were collected from direct field sampling by the authors (MSF,
142 BNB, and HJ) and game rangers of the Department of Environment (DoE), and also from camera-
143 trap photographs obtained during 2010 – 2017. Altogether, 632 and 680 occurrence points were
144 compiled for Persian leopard and Asiatic cheetah, respectively (Table 1), covering the full
145 distribution of the species in Iran. Often, available data of the species' locations are spatially biased
146 toward areas easily assessed and/or better surveyed. In this situation, spatial autocorrelation among
147 locations can result in biased parameter estimates and over-representation of some regions
148 (Dormann et al. 2007). We ran a Global Moran's I test to assess the spatial autocorrelation of the
149 occurrence points across the study area. To address auto-correlation arising from the spatial-
150 dependency of the clumping points, we followed a spatial filtering procedure (Kramer-Schadt et
151 al. 2013) in which multiple points within a 5-km distance (Farhadinia et al. 2015) were removed.
152 After this spatial filtering 423 and 205 occurrence points of the two species were retained for SDM
153 modelling. For both species, presence locations were obtained through a long-term and continuous
154 monitoring program in all potential habitats. Therefore we are confident that our dataset doesn't
155 suffer significant sampling bias and incompleteness.

156 **Explanatory variables**

157 Four categories of environmental factors including land cover, prey availability, anthropogenic
158 and topographic variables were used in SDM. Land cover variables, including dense to moderate
159 density forest, scrub-shrub land, sparse vegetation, unvegetated bare lands (e.g. playas and salt
160 lands) and cropland, were extracted from a land cover map of Iran produced by Iranian Forests,
161 Ranges and Watershed Management Organization (IFRWO, 2010). A moving window procedure
162 was used to calculate the proportion of each cover type within a 5 × 5 km grid.

Small to medium-sized ungulates, including roe deer (*Capreolus capreolus*, Linnaeus 1758), red deer (*Cervus elaphus*, Linnaeus 1758), bezoar goat (*Capra aegagrus*, Erxleben 1777), wild sheep (*Ovis orientalis*, Linnaeus 1758), goitered gazelle (*Gazella subgutturosa*, Güldenstädt 1780) and chinkara (*G. bennettii*, Sykes 1831), are the main prey of Persian leopard and Asiatic cheetah in Iran (Farhadinia and Hemami 2010; Farhadinia et al. 2018a). Prey distribution data were obtained from Karami et al. (2012). We overlaid shapefiles of the distribution of these prey species and calculated distance to areas known to support them to obtain a composite map of their distribution in Iran.

To include the anthropogenic effects in the species distribution models, we used the human footprint model (Sanderson et al. 2002) which combines data on population density and the presence of human infrastructure (i.e., road networks, land transformation, and human access). We used the Shuttle Radar Topography Mission (SRTM) elevation model (http://srtm.csi.cgiar.org) to measure elevation and topographic roughness (i.e., the standard deviation of the elevation of all raster cells within a grid of 5 × 5 km). All the explanatory variables were resampled to a cell size of 1 × 1 km and projected to a Lambert conformal conic projection. Pairwise Pearson correlation analysis was used to evaluate multi-collinearity among predictors, revealing no evidence of high multi-collinearity (pairwise correlation coefficient for all predictors < 0.7).

Species distribution modelling

To develop distribution models, we used two regression-based models including generalized linear models (GLM) and generalized additive models (GAM), together with two high-performing machine learning methods, generalized boosted models (GBM) and maximum entropy modeling (MaxEnt). We then combined the resulting models into an ensemble model using the *biomod2* package (Thuiller et al. 2009) in R 3.5 (R Development Core Team 2016). As all these models

186 require background data (e.g., pseudo-absence points), we generated 10,000 background points
187 randomly distributed across the extent of the study area, excepting cells with presence points. We
188 used 75% of occurrence points for training the models and the remaining 25% was used to test
189 their performance. The area under the curve (AUC) of the receiver operating characteristic (ROC)
190 plot was used to assess discrimination capacity and the true statistic skill (TSS) was used to
191 evaluate the classification accuracy of models. We then converted the continuous ensemble model
192 for each species to binary presence/absence map considering 10th percentile of suitability score at
193 the occurrence points of each species as the classification threshold. Using this threshold has two
194 advantages. First, it allowed us to exclude marginal points that occurred in areas with very low or
195 none-suitable habitat conditions, and second, it enabled us to take into account the probable spatial
196 bias or uncertainties caused by outlier occurrence points.

197 The reliability of gap analysis depends on how accurately habitat patches are recognized and
198 incorporated into the procedure. To identify habitat patches we leveraged two preliminary rules
199 based on previous findings on the spatial ecology of the species. First, we retained habitat patches
200 larger than the minimum patch size needed to hold breeding populations of leopards in Iran, ~ 250
201 km^2, (Ghoddousi et al. 2010). We then calculated the nearest-neighbor distance between patches
202 and removed unoccupied habitat patches that were greater than 200 km from occupied patches [~
203 equal to the longest movement has been recorded for Asiatic cheetah in arid ecosystems of Iran
204 (Farhadinia et al. 2016)] to exclude suitable patches from inaccessible areas.

205 ***Gap analysis and conservation prioritization***

206 We based the gap analysis framework upon two methods, the degree of protection granted to the
207 suitable landscapes by the CAs, and ranking them using the probability of connectivity (PC) index.
208 For the degree of protection granted by each conservation category, we calculated total

conservation coverage (i.e., the proportion of conserved areas from the total suitable habitats), and conservation efficiency (i.e., the proportion of conserved areas in each conservation category to the total area of that category). Of the metrics developed to date for measuring the importance of a given location in a connectivity network, the PC index, which is based on habitat availability, interpatch dispersal probabilities, and graph theory, performs best in practical landscape analysis (Saura and Pascual-Hortal 2007). The PC index reflects the probability that two animals randomly placed within the landscape fall into habitat areas that are reachable from each other (interconnected) given the set of habitat patches and the connections among them (Saura and Rubio 2010).

In this research, the latest shapefiles of Iran's conservation network including National Parks, Protected Areas, Wildlife Refuges, and No-Hunting Areas were overlaid with the binary presence/absence maps of the SDM analysis to calculate the extent of suitable areas within and outside the CA boundaries. The PC index was then used to prioritize CAs with the highest potential for maintaining ecological integrity and long-term population viability of the species. We assumed that each of the CAs functioned as habitat patches and used the extent of suitable habitats within them as patch attributes for calculating PC index values. PC was calculated using Conefor 2.6 software (Saura and Torne 2009). The Conefor also requires specification of distance-probability values corresponding to the dispersal ability of the target species. Given the measured dispersal distances of the species in previous studies (Farhadinia et al. 2018b), we chose 50 km as a median dispersal distance and 200 km as a maximum dispersal distance. Accordingly, as recommended by Saura and Torne (2009), we set distance-probability values of 0.5 and 0.05 for median and maximum dispersal distances, respectively. For more details on the calculation of PC index please see the Supporting Information.

232 To provide more insights into the importance of CAs for habitat connectivity we also
233 measured three fractions of the PC (dPC index, dPCintra, dPCflux and dPCconnector) separately.
234 These metrics assess different ways a CA can contribute to landscape connectivity (Saura and
235 Rubio 2010). Specifically, dPCintrak only measures intrapatch connectivity, while dPCflux
236 reflects both patch attributes (e.g., area of suitable habitats) and its position within the landscape,
237 and dPCconnector depends only on the topological position of a patch in the landscape (Saura and
238 Rubio 2010).

239

240 ## Results

241 All models showed high degrees of discrimination capacity (AUC > 0.85 and > 0.90 for Persian
242 leopard and Asiatic cheetah, respectively) and classification accuracy (TSS > 0.58 and > 0.68 for
243 Persian leopard and Asiatic cheetah, respectively). For both species, GBM obtained the highest
244 AUC and TSS values. Figure 1 represents the predicted suitable habitats of the species based on
245 an ensemble of the 4 SDMs. The conversion of continuous habitat suitability models to binary
246 presence/absence maps and the application of the two qualification criteria resulted in patches of
247 suitable habitat (Fig. 1b and 1d) with a total area of 316,984 km^2 and 97,338 km^2 for Persian
248 leopard and Asiatic cheetah, respectively. We also found a greater mean patch size for Asiatic
249 cheetah (4,424 km^2, 388 – 21,403 km^2) compared to Persian leopard (3,522 km^2, 257 – 110,348
250 km^2). Merging suitable patches indicated 400,071 km^2 of the region as the most suitable areas for
251 the occurrence of both of these two large carnivores (Online Appendix Fig. S3).

252 Gap analysis showed that the set of patches suitable for both species had intersected with 261
253 conservation units of the 376 CAs, which collectively cover 126,745 km^2 (31.6%) of the total

jointly suitable habitat for both species (Table 2). Among these 261 CAs, Protected Areas with a total number of 117 and a total area of 53,791 km^2 (13.4% of whole suitable habitats) showed the highest species representation, followed by NHAs (total number 102 and conservation coverage 33,763 km^2, 8.4%). WRs and NPs, with a total number of 23 and 19, and the total area of 30,344 km^2 (7.6%) and 8,845 km^2 (2.5%), respectively, had the lowest species representation (Table 2).

Regarding the spatial configuration of the conservation units, NHAs in total showed higher values of the PC index compared to the other conservation categories, although we found a high variability in the dPC of the conservation units, particularly for WRs (Table 3 and Fig. 2). We found that while WRs showed higher species representation (mean = 462 km^2, SD = 360 km^2) compared to NHAs (mean = 337 km^2, SD = 273 km^2), NPs (mean = 346 km^2, SD = 334 km^2), and PAs (mean = 363 km^2, SD = 330 km^2), NHAs surprisingly displayed the highest dPC value (mean = 0.75, SD = 0.67), followed by WRs (mean = 0.73, SD = 0.82), NPs (mean = 0.61, SD = 0.63) and PAs (mean = 0.53, SD = 0.65). In a similar pattern, comparing the contribution of CAs given the three fractions of the dPC index showed that WRs had the highest score for dPCflux, while NHAs had the highest values for dPCconnector (Table 3). It is worth mentioning that we found this pattern regardless of the outlier values (i.e., units with dPC values that were extreme based on a normal distribution of all conservation units). Our results also revealed that NPs and WRs had the strongest relationship between conservation coverage and dPC index (*adj.* R^2 = 0.77 and 0.63, respectively), and NHAs (*adj.* R^2 = 0.43) with the weakest relationship (Fig. 3).

Discussion

The goal of this study was to provide a more effective and comprehensive analysis of the gaps in the conservation area network by taking into account both representativeness and spatial connection of the CAs. While conservation coverage is widely discussed in the literature, there remains a substantial lack of methods and evidence regarding how the spatial configuration of conservation units influences the effectiveness of integrated networks of CAs.

Our research revealed three levels of bias in Iran's conservation network, all of which are also apparent on a global scale. In the first level, and similar to the findings of Joppa and Pfaff (2009), varying conservation effort has been invested in different components of the conservation network (more strictly protected areas, such as National Parks and Wildlife Refuges, versus less strictly conservation areas, such as Protected Areas and No-Hunting Areas), which has resulted in natural habitats being granted different levels of protection (we call this conservation bias). Four categories of CAs, including National Parks, Natural Heritage Sites, Wildlife Refuges and Protected Areas, have been established in Iran. Although different types of CAs are established to address different conservation targets and land use policies (Pressey et al. 2007), due to the higher costs of protection in Categories I and II, the global growth in gazetted CAs has frequently been concentrated in categories III-VI (Joppa and Pfaff 2009). As in the case of Iran, although NPs demonstrate higher protection efficiency (77%), they comprise only 7% of the total number of CAs and provide the least protection coverage (2.5%).

The CBD in general, and the flexibility of Aichi targets in particular, allow nations to design their own conservation ambitions and designations to reflect local opportunities and needs. Similarly, in Iran No-Hunting Areas, which are the newest category of CAs, have recently been designated to restore wildlife in areas where their populations have declined due to uncontrolled

297 hunting. NHAs have the main objective of empowering anti-poaching measures, unlike NPs or
298 WRs/PAs, where development and land use should be omitted or controlled, respectively.
299 Although more strictly protected areas have stronger legal guarantees against anthropogenic
300 impacts, conflicts with the desires of local communities often lead politicians to respond negatively
301 toward expansion or assignment of new CAs (Andam et al. 2013; Joppa and Pfaff 2009).
302 Interestingly, more strictly protected areas are not necessarily more protective of biodiversity (for
303 example see Andam et al. 2013; Ferraro et al. 2013). In this context, assigning less strictly
304 protected areas (e.g., NHAs in Iran, or IUCN's Category V and Category VI) in areas with long-
305 term human land-use and resource-utilization histories could be a pragmatic solution for the
306 recovery of vanishing species while affording fewer costs for conservation agencies.

307 Second, the establishment of CAs is concentrated in geographically remote and less
308 demanding landscapes, which we call location bias, was seen for Asiatic cheetahs. In contrast,
309 suitable habitats for the Persian leopard included higher levels of human activities, which is
310 explainable, in part, by the leopard's greater ability to coexist in human-dominated landscapes
311 (Farhadinia et al. 2018b; Soofi et al. 2018).

312 Finally, in addition to the conservation bias and location bias which have been convincingly
313 addressed in the literature (Joppa and Pfaff 2009; Venter et al. 2018; Watson et al. 2014), we
314 introduce 'network bias' as a new level of bias in conservation planning, where CAs are established
315 and/or expanded regardless of their position within the compositional structure of all conservation
316 units. We found that, based on a typical gap analysis (i.e., species representation), NHAs show
317 similar protection performance (conservation coverage) compared to the other CAs. However,
318 when spatial effectiveness is included in our evaluation by adding the concept of spatial

configuration, NHAs are revealed to be higher priorities for habitat connectivity and population integrity.

A potential criticism of metrics used to quantify landscape connectivity is that they tend to give high importance to large patches, and undervalue the contribution of connecting elements and/or stepping stone patches (Ferrari et al. 2007). One advantage of the PC index is that it enables quantification of how different critical patches are regarding both their habitat availability and topological position in the landscape (Saura and Rubio 2010). In the approach to gap analysis, we used this advantage of PC index and regressed the probability of connectivity onto habitat availability to identify how the different types of conservation networks vary for species representation and landscape configuration (see Table 3 and Fig. 3). The highest and the lowest relationship was found for NPs and NHAs, respectively. This pattern, which is also supported by results of dPC fractions (Table 3), reflects the fact that area and habitat suitability per unit contribute to the high scores given to NPs by the dPC index, while the high scores given to NHAs by the dPCconnector reflect their greater contribuition to network connectivity compared to the other conservation units. Consequently, our gap analysis reveals that the more strictly protected areas (i.e., NPs and WRs) display high protection performance regarding species representation, while the newly-introduced and less strictly protected areas (i.e., NHAs) are stepping stones providing critical connections across the CA network. Consistent with our results, (Khosravi et al. 2018) also emphasized the importance of NHAs as stepping stones for large carnivore habitat connectivity in the deserts of central Iran.

We used the probability of connectivity index to measure the landscape integrity of the CAs. Intrinsically, the PC index measures functional connectivity of the habitat patches through the landscape (Saura and Pascual-Hortal 2007) and has been widely applied to problems of landscape

conservation prioritization (Ahmadi et al. 2017; Visconti and Elkin 2009). It is worth mentioning that connectivity varies depending on the attributes of the target species or communities (Baguette et al. 2013). Accordingly, analyzing landscape connectivity is a species-specific process as it depends on the dispersal distance and behavioral response of the target species (e.g. Baguette et al. 2013; Cushman et al. 2012). While large carnivores with broad spatial requirements require comprehensive and large-scale management strategies, for movement-restricted species management activities could be downscaled to fine-scale structures such as hedgerow networks (Dondina et al. 2018). Nevertheless, addressing connectivity in conservation design requires assessing the complementarity of the components of a system to ensure the robustness of ecological functions. Landscape-scale approaches can account for the complexity of ecological functions, and so can enhance the capacity to designate elements of CA networks to best deliver desired conservation outcomes (Cushman 2006). Here we focused on conservation planning of the CAs within a large-scale management perspective and utilized the concept of focal species (e.g., dominant flagship and/or umbrella species) which may provide surrogates for a wide variety of subdominant species (Macdonald et al. 2017), which in turn rationalizes the use of the PC index for regional multi-species conservation planning. Notwithstanding, it is germane to consider that this line of reasoning suggests more research and necessitates consideration of the results of studies for a wide range of species.

Based on our suitability maps, Persian leopards mainly occur in mountainous landscapes, whereas Asiatic cheetahs are predominantly found in arid lowland landscapes. The species distribution models we produced in this study correspond well with findings of previous researches (Ahmadi et al. 2017; Farhadinia et al. 2015; Gavashelishvili and Lukarevskiy 2008; Khosravi et al. 2019), in particular, preference of these species for rugged landscapes with high availability of

prey species and the avoidance of human-dominated areas (see the response curve of the variables provided in Online Appendix Fig. S1 and Fig. S2). However, the two species showed different patterns of habitat selection in relation to human pressure. Although Asiatic cheetahs avoid areas even with minor human presence, Persian leopards have moderate tolerance towards humans in their habitat. Accordingly, conflict with communities due to livestock depredation is more widely reported for Persian leopards than Asiatic cheetahs (Babrgir et al. 2017; Soofi et al. 2018).

Conclusions

Expansion of current CAs and designating new conservation-oriented areas has been emphasized as an important strategy to mitigate the impacts of human society on biodiversity (COP 2010). Due to the shortage of funding resources and staff, as well as external threats from human land use changes (Hearn et al. 2018; Joppa and Pfaff 2009), efforts to assess the effectiveness of CAs and to strategically allocate management activities would greatly benefit from an assessment of the collective effectiveness of the entire network of CAs (Le Saout et al. 2013). In this research, the network of CAs of Iran was considered as a model for our new approach to gap analysis. This approach evaluates the different categories of CAs given their level of protection, species representation, and network connectivity. We showed that this approach is a simple and efficient method for rapid assessment of completeness and effectiveness of CA networks. Although species representation is widely used, we showed that taking into account both representativeness and spatial configuration of the CAs can effectively enhance conservation planning and can help address three main biases, particularly the network bias. The wide range of conservation area categories on a global scale, as well as the necessity to consider these three aspects in any gap analysis, suggests that our approach may be useful as a global model applicable to other species and geographical contexts.

Acknowledgments We are grateful for the financial and technical support of the DoE of Iran, the Global Environmental Facilities (GEF), the United Nations Development Program (UNDP), and the Wildlife Conservation Society (WCS). We thank K. Baradarani and A. Taktehrani for their help in collecting leopard occurrence data. Our special thanks go to the game guards of the DoE who helped us in field sampling. MA received a sabbatical research fund from the Ministry of Sciences, Research and Technology of Iran for a 6-month research in Swiss Federal Research Institute (WSL). MSF was supported by a research fellowship from Oxford Martin School at the University of Oxford.

References

Ahmadi M, Nezami Balouchi B, Jowkar H, Hemami MR, Fadakar D, Malakouti-Khah S, Ostrowski S (2017) Combining landscape suitability and habitat connectivity to conserve the last surviving population of cheetah in Asia. Diversity and Distributions 23:592–603. https://doi.org/10.1111/ddi.12560

Andam KS, Ferraro PJ, Hanauer MM (2013) The effects of protected area systems on ecosystem restoration: a quasi- experimental design to estimate the impact of Costa Rica's protected area system on forest regrowth. Conservation Letters 6:317-323

Araújo MB, Lobo JM, Moreno JC (2007) The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. Conservation Biology 21:1423-1432. https://doi.org/10.1111/j.1523-1739.2007.00827.x

Ashrafzadeh MR, Khosravi R, Ahmadi M, Kaboli M (2018) Landscape heterogeneity and ecological niche isolation shape the distribution of spatial genetic variation in Iranian brown bears, Ursus arctos (Carnivora: Ursidae). Mammalian Biology 93:64-75

Babrgir S, Farhadinia MS, Moqanaki EM (2017) Socio-economic consequences of cattle predation by the Endangered Persian leopard Panthera pardus saxicolor in a Caucasian conflict hotspot, northern Iran. Oryx 51:124-130

Baguette M, Blanchet S, Legrand D, Stevens VM, Turlure C (2013) Individual dispersal, landscape connectivity and ecological networks. Biological Reviews 88:310-326

Carroll C, Noss RF, Paquet PC (2001) Carnivores as focal species for conservation planning in the Rocky Mountain region. Ecological applications 11:961-980

CBD (2010) The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets, Nagoya, Japan, 18 to 29 October 2010.

COP C (2010) Decision X/2: Strategic Plan for Biodiversity 2011-2020. Convention on Biological Diversity, Nagoya, Japan.

Cushman SA (2006) Effects of habitat loss and fragmentation on amphibians: a review and prospectus. Biological Conservation 128:231-240
Cushman SA et al. (2018) Prioritizing core areas, corridors and conflict hotspots for lion conservation in southern Africa. PloS one 13:e0196213
Cushman SA, Landguth EL, Flather CH (2012) Evaluating the sufficiency of protected lands for maintaining wildlife population connectivity in the US northern Rocky Mountains. Diversity and Distributions 18:873-884
Cushman SA, Macdonald EA, Landguth EL, Malhi Y, Macdonald DW (2017) Multiple-scale prediction of forest loss risk across Borneo. Landscape ecology 32:1581-1598
Dondina O, Saura S, Bani L, Mateo-Sánchez MC (2018) Enhancing connectivity in agroecosystems: focus on the best existing corridors or on new pathways? Landscape Ecology 33:1741-1756
Dormann CF et al. (2007) Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30:609-628
Farhadinia M, Hemami M-R (2010) Prey selection by the critically endangered Asiatic cheetah in central Iran. Journal of Natural History 44:1239-1249
Farhadinia MS, Ahmadi M, Sharbafi E, Khosravi S, Alinezhad H, Macdonald DW (2015) Leveraging trans-boundary conservation partnerships: persistence of Persian leopard (*Panthera pardus saxicolor*) in the Iranian Caucasus. Biological Conservation 191:770–778
Farhadinia MS et al. (2016) Wandering the barren deserts of Iran: illuminating high mobility of the Asiatic cheetah with sparse data. Journal of Arid Environments 134:145-149
Farhadinia MS et al. (2017) The critically endangered Asiatic cheetah Acinonyx jubatus venaticus in Iran: a review of recent distribution, and conservation status. Biodiversity and Conservation 26:1027-1046
Farhadinia MS, Johnson PJ, Hunter LT, Macdonald DW (2018a) Persian leopard predation patterns and kill rates in the Iran–Turkmenistan borderland. Journal of Mammalogy 99:713-723
Farhadinia MS, Johnson PJ, Macdonald DW, Hunter LT (2018b) Anchoring and adjusting amidst humans: Ranging behavior of Persian leopards along the Iran-Turkmenistan borderland. PLoS ONE 13:e0196602
Ferrari JR, Lookingbill TR, Neel MC (2007) Two measures of landscape-graph connectivity: assessment across gradients in area and configuration. Landscape ecology 22:1315-1323
Ferraro PJ, Hanauer MM, Miteva DA, Canavire-Bacarreza GJ, Pattanayak SK, Sims KR (2013) More strictly protected areas are not necessarily more protective: evidence from Bolivia, Costa Rica, Indonesia, and Thailand. Environmental Research Letters 8:025011
Franklin J (2010) Mapping species distributions: spatial inference and prediction. Cambridge University Press,
Gaston KJ, Jackson SF, Cantú-Salazar L, Cruz-Piñón G (2008) The ecological performance of protected areas. Annual review of ecology, evolution, and systematics 39:93-113
Gavashelishvili A, Lukarevskiy V (2008) Modelling the habitat requirements of leopard Panthera pardus in west and central Asia. Journal of Applied Ecology 45:579-588
Ghoddousi A, Hamidi AK, Ghadirian T, Ashayeri D, Khorozyan I (2010) The status of the endangered Persian leopard Panthera pardus saxicolor in Bamu National Park, Iran. Oryx 44:551-557
Guisan A et al. (2013) Predicting species distributions for conservation decisions. Ecology letters 16:1424-1435
Hearn AJ et al. (2018) Evaluating scenarios of landscape change for Sunda clouded leopard connectivity in a human dominated landscape. Biological Conservation 222:232-240
Hemami M-R, Esmaeili S, Brito JC, Ahmadi M, Omidi M, Martínez-Freiría F (2018) Using ecological models to explore niche partitioning within a guild of desert felids. Hystrix, the Italian Journal of Mammalogy 29:216-222
Jenkins CN, Pimm SL, Joppa LN (2013) Global patterns of terrestrial vertebrate diversity and conservation. Proceedings of the National Academy of Sciences 110:E2602-E2610

473 Jenkins CN, Van Houtan KS, Pimm SL, Sexton JO (2015) US protected lands mismatch biodiversity
474 priorities. Proceedings of the National Academy of Sciences 112:5081-5086
475 Jennings MD (2000) Gap analysis: concepts, methods, and recent results. Landscape ecology 15:5-20
476 Joppa LN, Pfaff A (2009) High and far: biases in the location of protected areas. PloS one 4:e8273
477 Juffe-Bignoli D et al. (2014) Protected planet report 2014. UNEP-WCMC: Cambridge, UK 11
478 Karami M, Ghadirian T, Faizolahi K (2012) The atlas of mammals of Iran. Department of Environment.
479 Tehran, Iran,
480 Khosravi R, Hemami M-R (2019) Identifying landscape species for ecological planning. Ecological
481 indicators 99:140-148
482 Khosravi R, Hemami M-R, Cushman SA (2019) Multi-scale niche modeling of three sympatric felids of
483 conservation importance in central Iran. Landscape Ecology 34:2451-2467
484 Khosravi R, Hemami MR, Cushman SA (2018) Multispecies assessment of core areas and connectivity of
485 desert carnivores in central Iran. Diversity and Distributions 24:193-207
486 Kiabi BH, Dareshouri BF, Ghaemi RA, Jahanshahi M (2002) Population status of the Persian leopard
487 (Panthera pardus saxicolor Pocock, 1927) in Iran. Zoology in the Middle East 26:41-47
488 Kolahi M, Sakai T, Moriya K, Makhdoum MF (2012) Challenges to the future development of Iran's
489 protected areas system. Environmental management 50:750-765
490 Kramer-Schadt S et al. (2013) The importance of correcting for sampling bias in MaxEnt species
491 distribution models. Diversity and Distributions 19:1366–1379.
492 http://dx.doi.org/10.1111/ddi.12096
493 Le Saout S et al. (2013) Protected areas and effective biodiversity conservation. Science 342:803-805
494 Macdonald DW et al. (2018) Multi-scale habitat selection modeling identifies threats and conservation
495 opportunities for the Sunda clouded leopard (Neofelis diardi). Biological Conservation 227:92-103
496 Macdonald E et al. (2017) Identifying ambassador species for conservation marketing. Global ecology and
497 conservation 12:204-214
498 Maiorano L, Falcucci A, Boitani L (2006) Gap analysis of terrestrial vertebrates in Italy: priorities for
499 conservation planning in a human dominated landscape. Biological Conservation 133:455-473
500 Meyer SR, Beard K, Cronan CS, Lilieholm RJ (2015) An analysis of spatio-temporal landscape patterns
501 for protected areas in northern New England: 1900–2010. Landscape ecology 30:1291-1305
502 Pressey RL, Cabeza M, Watts ME, Cowling RM, Wilson KA (2007) Conservation planning in a changing
503 world. Trends in Ecology & Evolution 22:583-592.
504 http://www.sciencedirect.com/science/article/pii/S0169534707002807
505 R Development Core Team (2016) R: A language and environment for statistical computing. R Foundation
506 for Statistical Computing, Vienna, Austria.
507 Rodrigues AS et al. (2004a) Global gap analysis: priority regions for expanding the global protected-area
508 network. BioScience 54:1092-1100
509 Rodrigues AS et al. (2004b) Effectiveness of the global protected area network in representing species
510 diversity. Nature 428:640
511 Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G (2002) The human footprint
512 and the last of the wild: the human footprint is a global map of human influence on the land surface,
513 which suggests that human beings are stewards of nature, whether we like it or not. AIBS Bulletin
514 52:891-904
515 Santini L, Di Marco M, Boitani L, Maiorano L, Rondinini C (2014) Incorporating spatial population
516 structure in gap analysis reveals inequitable assessments of species protection. Diversity and
517 distributions 20:698-707
518 Santini L, Saura S, Rondinini C (2016) Connectivity of the global network of protected areas. Diversity and
519 Distributions 22:199-211
520 Saura S, Bertzky B, Bastin L, Battistella L, Mandrici A, Dubois G (2018) Protected area connectivity:
521 Shortfalls in global targets and country-level priorities. Biological conservation 219:53-67

Saura S, Pascual-Hortal L (2007) A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. Landscape and Urban Planning 83:91-103

Saura S, Rubio L (2010) A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. Ecography 33:523-537

Saura S, Torne J (2009) Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. Environmental Modelling & Software 24:135-139

Soofi M et al. (2018) Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology 56:365-374. https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.13266

Thuiller W, Lafourcade B, Engler R, Araújo MB (2009) BIOMOD–a platform for ensemble forecasting of species distributions. Ecography 32:369–373

Venter O, Magrach A, Outram N, Klein CJ, Possingham HP, Di Marco M, Watson JE (2018) Bias in protected- area location and its effects on long- term aspirations of biodiversity conventions. Conservation biology 32:127-134

Visconti P et al. (2019) Protected area targets post-2020. Science 364:239-241

Visconti P, Elkin C (2009) Using connectivity metrics in conservation planning–When does habitat quality matter? Diversity and Distributions 15:602-612

Watson JEM, Dudley N, Segan DB, Hockings M (2014) The performance and potential of protected areas. Nature 515:67. http://dx.doi.org/10.1038/nature13947

Yousefi M, Ahmadi M, Nourani E, Behrooz R, Rajabizadeh M, Geniez P, Kaboli M (2015) Upward Altitudinal Shifts in Habitat Suitability of Mountain Vipers since the Last Glacial Maximum. PloS one 10:e0138087

Table legend:

Table 1. The number of presence points collected to be used in SDM.

	Total observations	Direct field sampling	Camera traps
Persian leopard	632	498	134
Asiatic cheetah	680	485	195

Table 2. Total area and proportion of protection granted to the suitable habitats by Iran's conservation network with respect to their corresponding IUCN categories. Conservation coverage: ratio of conserved habitats to the total suitable habitats. Conservation efficiency: ratio of conserved habitats to the total area of each conservation unit.

Iran CAs	**IUCN Category**	**Number**	**Area (km^2)**	**Conservation coverage (km^2)**	**Conservation coverage (%)**	**Conservation efficiency (%)**
National Park	Category II	19	11426	8845	2.5	77.4
Wildlife Refuge	Category IV	23	49480	30344	7.6	61.3
Protected Area	Category IV-VI	117	77104	53791	13.4	69.8
No-hunting Area	Category V	102	54047	33763	8.4	62.4
Total		261	192059	126745	31.6	65.9

Iran's conservation network are those with an intersection with suitable habitat patches

Table 3. Mean values of dPC index and its three fractions (intra, flux and connector) calculated for different categories of conservation areas. NPs: National Parks, WRs: Wildlife Refuges, PAs: Protected Area, NHAs: No-hunting Area.

	dPC		dPCintra		dPCflux		dPCconnector	
	50-km	200-km	50-km	200-km	50-km	200-km	50-km	200-km
NPs	0.61	0.63	0.02	0.01	0.45	0.49	0.14	0.13
WRs	0.73	0.74	0.02	0.02	0.52	0.54	0.19	0.18
PAs	0.53	0.58	0.01	0.06	0.42	0.41	0.10	0.11
NHAs	0.75	0.73	0.01	0.03	0.46	0.43	0.28	0.27

Figure Legends:

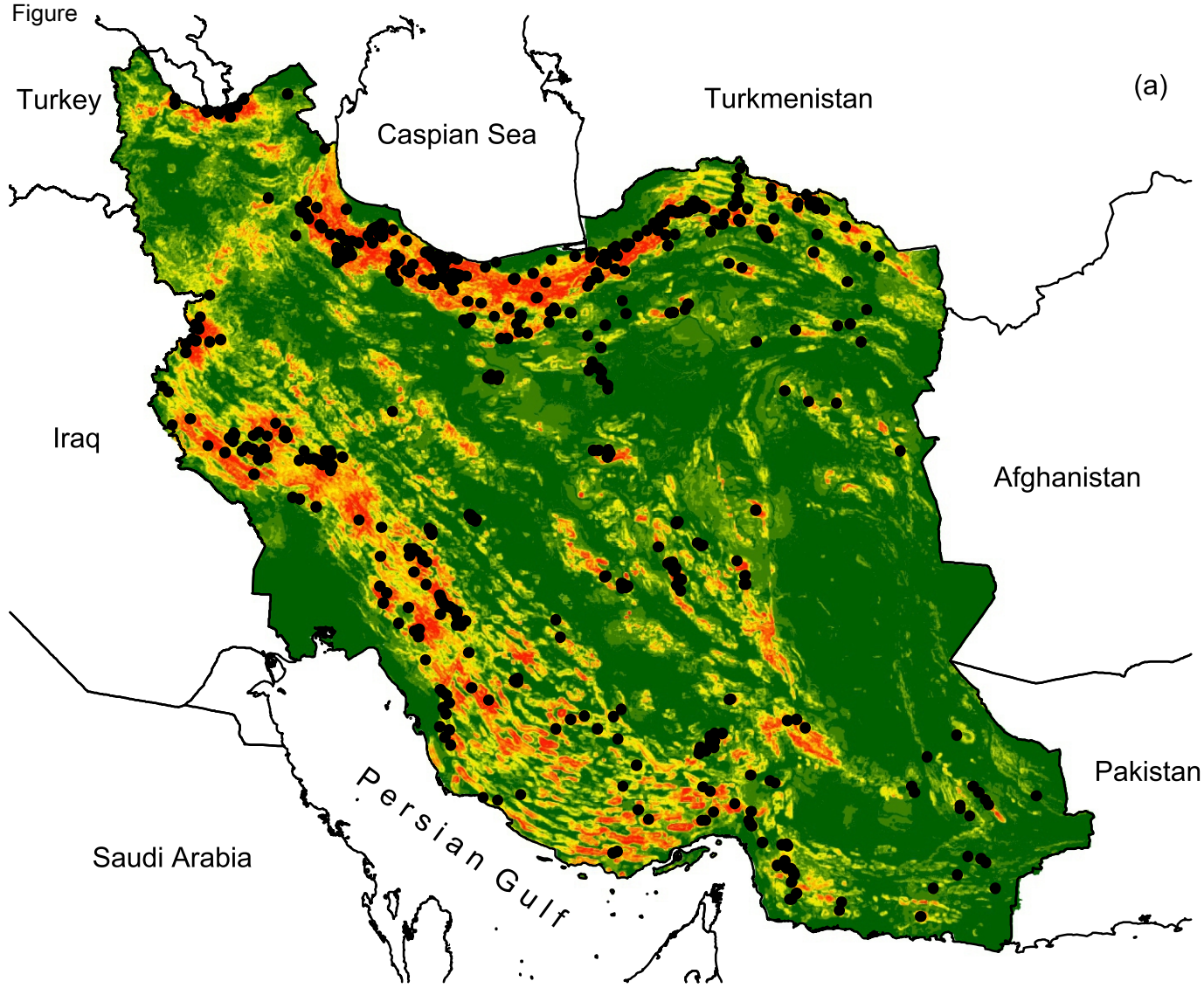
Fig. 1 Habitat suitability of Persian leopard (a, b) and Asiatic cheetah (c, d) in southwestern Asia. Continuous maps (a, c) were derived based on an ensemble distribution model of GLM, GAM, GBM and MaxEnt models. Binary maps (b, d) generated to identify core habitat patches using 10-percentile suitability at occurrence points of each species as a presence/absence threshold

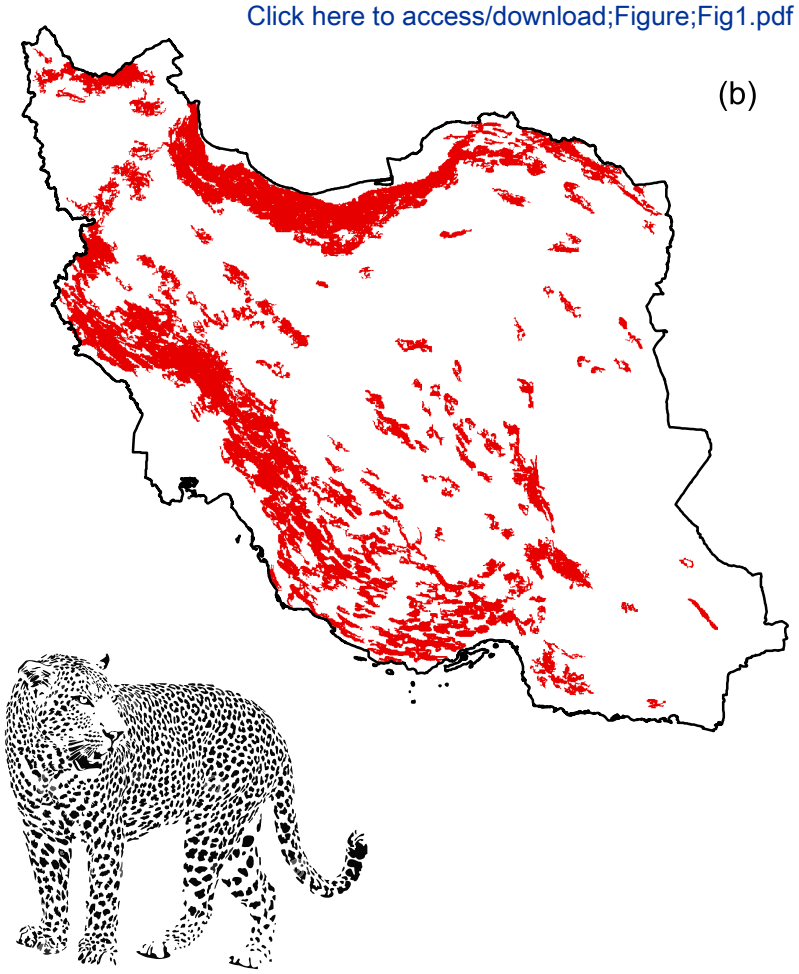
Fig. 2 Scatterplot of species representation (suitability coverage) and the probability of connectivity index (dPC) of the No-hunting Areas (NHAs), National Parks (NPs), Protected Areas (PAs) and Wildlife Refuges (WRs). dPC scores were calculated based on a median (50km) and maximum dispersal distance (200 km) of the species

Fig. 3 Nonlinear regression between species representation (suitability coverage) and the probability of connectivity index (dPC) of Iranian conservation units. dPC scores were calculated based on a median (50km) and maximum dispersal distance (200 km) of the species. NHAs: No-Hunting Areas, NPs: National Parks, PAs: Protected Areas, WRs: Wildlife Refuges

Figure

Click here to access/download;Figure;Fig1.pdf





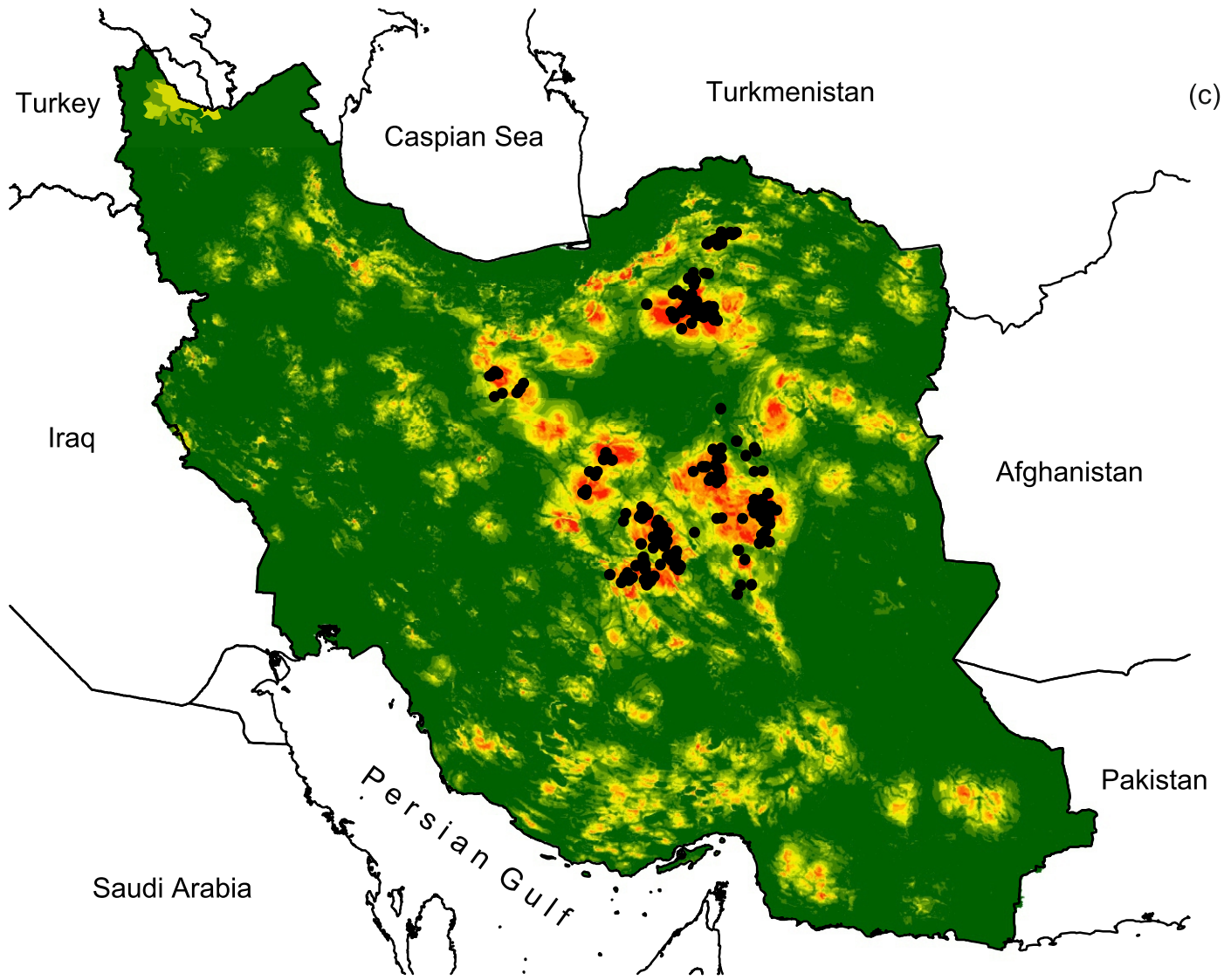
Occurrence points

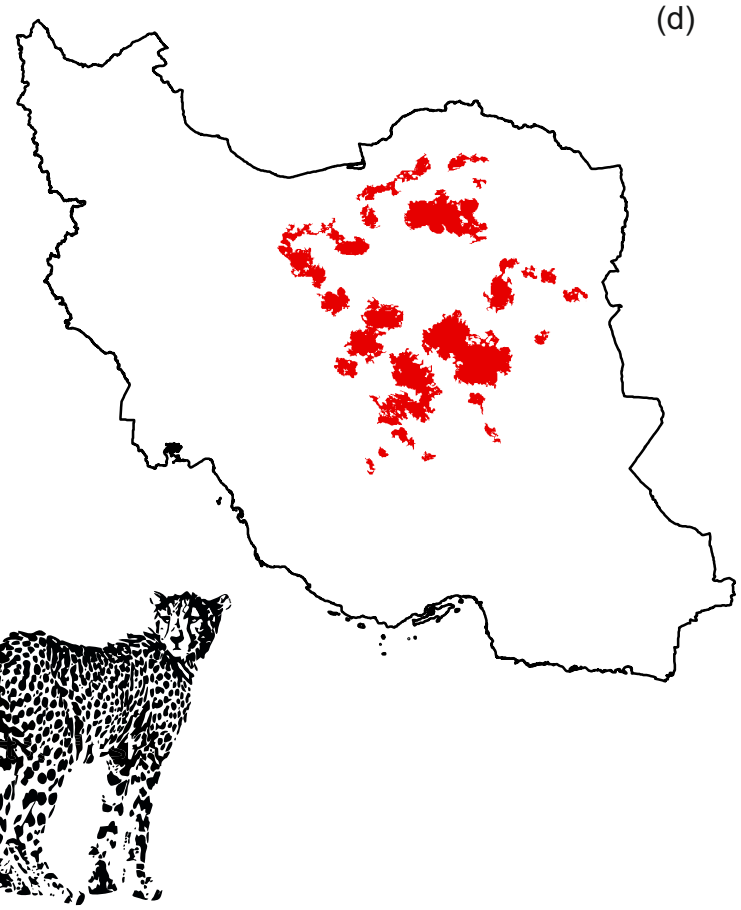
Core habitats

Habitat suitability

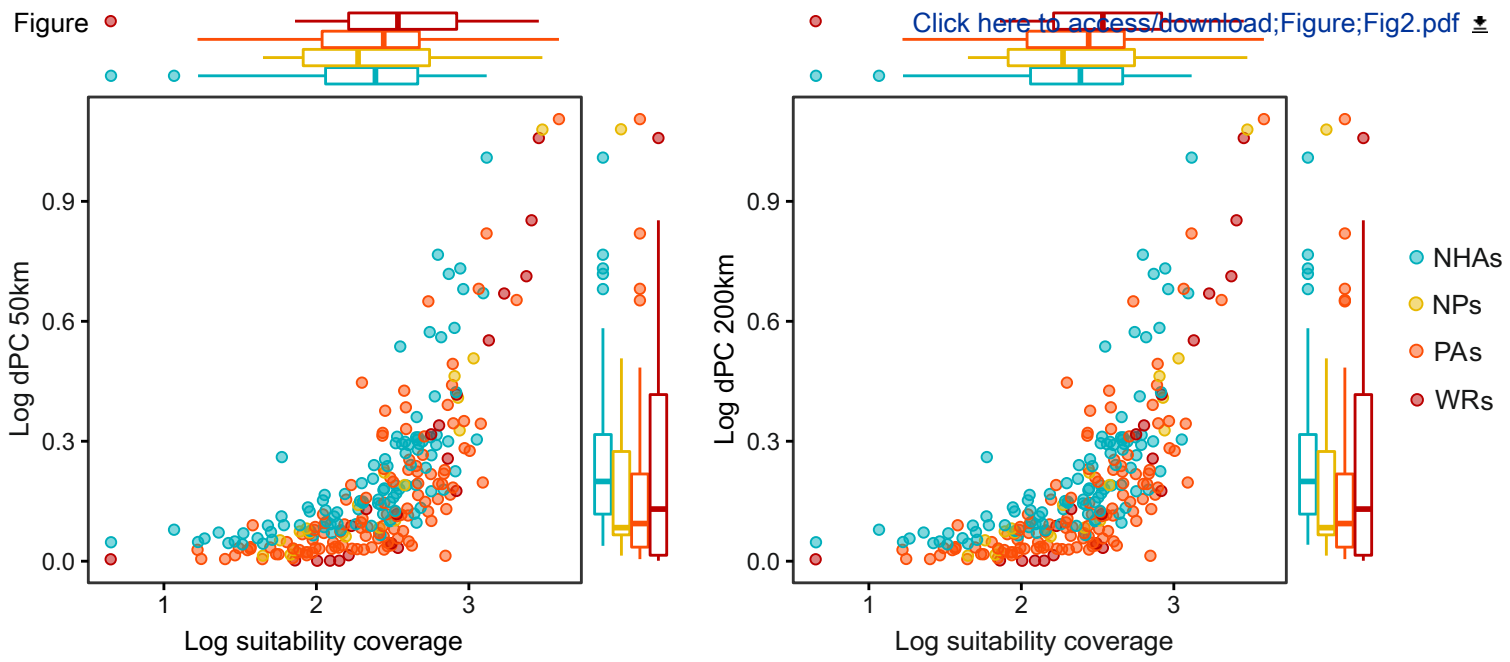
Low

High



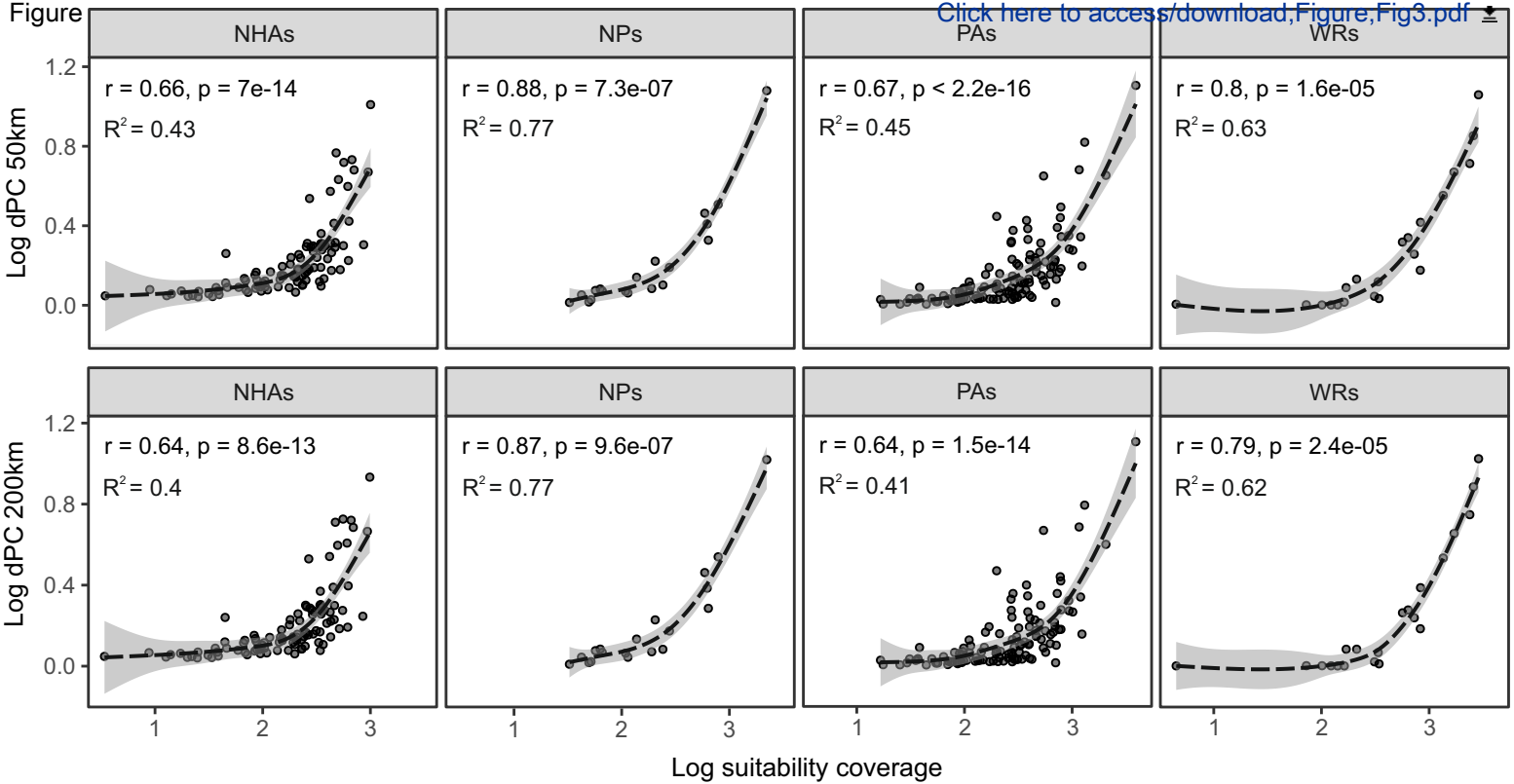


Figure


Click here to access/download;Figure;Fig2.pdf
Log dPC 50km
Log dPC 200km
Log suitability coverage
Log suitability coverage
0.0
0.3
0.6
0.9
1
2
3
NHAs
NPs
PAs
WRs

Figure

Click here to access/download,Figure,Fig3.pdf



Click here to access/download
Supplementary material
Supplementary material.docx