UNIVERSITI PUTRA MALAYSIA

MODELING REGIONAL CUMULATIVE EFFECTS OF LAND USE AND LAND COVER VARIATIONS IN RELATION TO PERSISTENCE OF THE PERSIAN LEOPARD (Panthera pardus saxicolor) IN IRAN

AREZOO SANEI

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By

AREZOO SANEI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2018

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DEDICATION

Let's not wish the leopard to exit from the gate of creation,
And we should know that life lacked something, if the worms did not exist,
And without a scratch on its bark, the law of tree would be offended,
And if there were no death, our hands would search for something else,
And we should know that before corals, a void existed in the thoughts of the seas
(*Sepehri, S. 1964. The water's footsteps*)

I dedicate this thesis to the king of the mountains of Iran,
the Persian leopard.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MODELING REGIONAL CUMULATIVE EFFECTS OF LAND USE AND LAND COVER VARIATIONS IN RELATION TO PERSISTENCE OF THE PERSIAN LEOPARD (*Panthera pardus saxicolor*) IN IRAN

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March 2018

Chairman : Professor Mohamed Zakaria Hussin, PhD
Faculty : Forestry

Cumulative effect of land use and land cover changes on the persistence of the Persian leopard (*Panthera pardus saxicolor*) in Iran is not characterized and formulated so far. Current research is concerned with developing an innovative species and region specific methodological approach to predict cumulative effect of the land use and land cover variations on the Persian leopard persistence. The research is a countrywide practice conducted in a regional basis in Iran with three provinces selected for the relative ground validation techniques. Accordingly, three main research sections are developed to assess the data and information required for formulation of the models. In the first section the provinces are innovatively classified into five significantly dissimilar regions in terms of environmental variations based on the wide distribution of the Persian leopard in at least 30 out of 31 provinces of Iran. Sufficient well distributed leopard presence records together with 17 natural and human variables were used to develop potential habitat predictive maps in a regional basis using MaxEnt software. Variables are tested for possible correlation among them and models were evaluated for the predictive performance. The research null hypothesis regarding no significant regional variability of permutation importance of

the research variables in the best fitted predictive models, is accepted. Two landscape corridors to improve the leopard distribution pattern connectivity in a metapopulation scale are identified.

The next research section is aimed to validate the developed best fitted predictive models in the earliest section via ground validation techniques to eventually assess a threshold value indicating the minimum suitability rate for the leopard presence. In this regards, three threshold rules including equal training sensitivity and specificity, maximum training sensitivity plus specificity and minimum training presence were selected for the purpose of binary classification of the predictive maps. Accordingly, field surveys (e.g. camera trapping for 2,541 trap nights, sign surveys, interviews with local knowledgeable people) together with mapping and overlays concentrated on the errors of omission across three selected provinces in (1) North-East containing Kopet Dag Mountains, (2) North-West located in the Caucasus Ecoregion and (3) adjacent to the Persian Gulf in southernmost part of the leopard range in the country. The results indicate that the sensitivity and specificity based threshold rules show more accuracy comparing to the minimum training presence rule with notable overestimation of the suitability rates. Eventually, habitat suitability rate of 0.3 on the developed predictive maps was identified as a value to safely recognize the actual potential habitats with confirmed significance for conservation planning.

The latest section of the research is aimed to develop empirically fitted species and region specific models and relative threshold values using the findings of previous research sections to assess cumulative effects of land use and land cover variables on the regional persistence of the Persian leopard. The Principle Component Analysis and regression curve estimation were used as the main statistical techniques in this section. Two types of innovative models with relative threshold values were developed. The first type uses habitat suitability rates while the second type uses density of the land use and land cover variables. Subsequently, current status of each province in relation to the Persian leopard regional persistence is assessed. Accordingly, adjustments are required in cumulative effect of land use and land cover variables to improve the quality of two identified landscape corridors in the earliest section as their current status is significantly farther than the threshold level to ascertain regional persistent of the Persian leopard. Findings of this research support the earlier hypothesis indicating

that the leopard range in Iran is in the process of splitting to the northern and southern fragmented parts.

Research sections developed in this study contribute significantly to the current knowledge about the Persian leopard status and the conservation requirements. The developed approach provides a helpful insight to the decision makers to wisely consider wildlife friendly solutions for development activities and prevent negative cumulative effect of land use and land cover changes on leopard persistence in each region. These innovative models can be adjusted to be used for the conservation purposes in other countries of the Persian leopard range in southwest Asia. The approach can be used to develop similar species and region specific models addressing other regions and large cat species.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN KESAN KUMULATIF SERANTAU VARIASI GUNA TANAH DAN LITUP TANAH BERKAITAN DENGAN KEHADIRAN BERTERUSAN HARIMAU BINTANG PARSI (*Panthera pardus saxicolor*) DI IRAN

Oleh

AREZOO SANEI

Mac 2018

Pengerusi : Profesor Mohamed Zakaria Hussin, PhD
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Kesan kumulatif perubahan guna tanah dan litup tanah terhadap kehadiran berterusan harimau bintang Parsi (*Panthera pardus saxicolor*) di Iran belum diciri dan dan diformulasikan setakat ini. Penyelidikan semasa mengambil berat tentang penemuan suatu pendekatan inovatif metodologi terhadap spesies dan wilayah spesifik untuk meramalkan kesan kumulatif guna tanah dan variasi litup tanah terhadap kehadiran berterusan harimau bintang Parsi. Penyelidikan ini adalah satu amalan di seluruh negara yang dijalankan berasaskan serantau di Iran dengan tiga wilayah yang dipilih untuk menjalankan teknik pengesahan tanah. Tiga bahagian penyelidikan utama dibangunkan dalam merumuskan model bagi data dan informasi yang diperlukan. Dalam bahagian pertama, wilayah-wilayah ini diklasifikasikan secara inovatif ke dalam lima wilayah yang jauh berbeza dari segi variasi alam sekitar berdasarkan luas taburan harimau bintang Parsi dalam sekurang-kurangnya 30 dari 31 wilayah Iran. Rekod kehadiran harimau yang mencukupi dengan 17 pembolehubah semulajadi dan manusia digunakan untuk membangunkan peta ramalan habitat yang berpotensi secara serantau menggunakan perisian MaxEnt. Pembolehubah

diuji untuk menentukan kemungkinan korelasi antara mereka dan model dinilai untuk prestasi ramalan. Hipotesis nol penyelidikan iaitu ketiadaan signifikan dalam kepelbagaian permutasi serantau sebagai pembolehubah penting penyelidikan adalah model ramalan terbaik adalah diterima. Dua koridor landskap untuk meningkatkan kesalinghubungan corak taburan harimau dalam skala metapopulasi dikenalpasti.

Bahagian penyelidikan yang seterusnya bertujuan untuk mengesahkan model ramalan terbaik yang telah dibangunkan di bahagian sebelum ini melalui teknik pengesahan lapangan untuk menilai nilai ambang yang menunjukkan kadar kesesuaian minimum bagi kehadiran harimau bintang. Dalam hal ini, tiga peraturan ambang termasuk sensitiviti dan kekhususan latihan yang saksama, sensitiviti latihan maksimum bersama spesifisiti dan kehadiran latihan minimum telah dipilih untuk tujuan klasifikasi binari peta ramalan. Oleh itu, tinjauan lapangan (contohnya, pemerangkapan kamera untuk 2,541 malam perangkap, tinjauan jejak, wawancara dengan orang tempatan yang berpengetahuan) bersama-sama dengan pemetaan dan lapisan tertumpu kepada pengecualian ralat di tiga wilayah terpilih di (1) Timur Laut yang mengandungi Pergunungan Kopet Dag, (2) Barat Laut yang terletak di Caucasus Ecoregion dan (3) bersebelahan dengan Teluk Parsi di bahagian paling selatan dari populasi harimau bintang di negara ini. Hasil keputusan menunjukkan bahawa sensitiviti dan spesifisiti berasaskan peraturan ambang menunjukkan ketepatan lebih tinggi berbanding dengan kehadiran latihan minimum dengan jangkaan yang ketara mengenai kadar kesesuaian. Akhirnya, kadar kesesuaian habitat 0.3 di atas peta ramalan yang dibangunkan telah dikenal pasti sebagai nilai selamat untuk mengenali habitat potensi sebenar dengan perancangan pemuliharaan yang signifikan sahnya.

Bahagian terakhir penyelidikan ini bertujuan untuk membangunkan spesies yang terikat secara empirikal dan model khusus serantau serta nilai ambang relatif menggunakan penemuan bahagian penyelidikan terdahulu untuk menilai kesan kumulatif penggunaan tanah dan pembolehubah litup tanah atas kehadiran serantau harimau Parsi. Prinsipal Analisis Komponen dan teknik anggaran keluk regresi digunakan sebagai teknik analisis utama dalam bab ini. Dua jenis model inovatif dengan nilai ambang relatif telah dibangunkan. Jenis pertama menggunakan kadar kesesuaian habitat sementara jenis kedua menggunakan kepadatan penggunaan tanah dan pembolehubah litup tanah. Selanjutnya, status semasa setiap wilayah

berkaitan dengan kehadiran serantau harimau Parsi dinilai. Pelarasan diperlukan dalam kesan kumulatif pembolehubah guna tanah dan litup tanah untuk meningkatkan kualiti koridor landskap yang dikenal pasti di bab terawal sebagai status semasa mereka adalah jauh lebih rendah daripada tahap ambang untuk menentukan kehadiran berterusan harimau Parsi di rantau ini. Penemuan penyelidikan ini menyokong hipotesis yang lebih awal yang menunjukkan bahawa banjaran taburan harimau bintang di Iran sedang dalam proses pemisahan ke bahagian utara dan selatan yang terbahagi.

Bahagian penyelidikan yang dibangunkan dalam kajian ini menyumbang dengan ketara kepada pengetahuan semasa tentang status harimau bintang Parsi dan keperluan pemuliharaan. Model yang dibangunkan ini menyediakan pandangam yang berguna kepada pembuat keputusan untuk mempertimbangkan secara bijaksana penyelesaian mesra hidupan liar untuk aktiviti pembangunan dan mengelakkan kesan kumulatif negatif guna tanah dan perubahan litup tanah di setiap wilayah. Model-model inovatif ini boleh diselaraskan untuk digunakan untuk tujuan pemuliharaan di negara-negara selain dari kawasan harimau bintang Parsi di Asia barat daya. Pendekatan ini boleh digunakan untuk membangunkan spesies yang serupa dan model spesifik wilayah yang meliputi kawasan dan spesies kucing besar lain.

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I certify that a Thesis Examination Committee has met on 29 March 2018 to conduct the final examination of Arezoo Sanei on her thesis entitled "Modeling Regional Cumulative Effects of Land Use and Land Cover Variations in Relation to Persistence of the Persian Leopard (*Panthera pardus saxicolor*) in Iran" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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Declaration of Members of Supervisory Committee

This to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as state din Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Professor Dr. Mohammad Zakaria Hussin

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Name of Member of Supervisory Committee: Associate Professor Dr. Abdullah Mohd

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LIST OF ABBREVIATIONS AND SYMBOLS

°	Degree
˚C	Degree Centigrade
%	Percent
‘	Minute
AMV	Assessed Model Value
ANOVA	Analysis of Variance
ASL	Above Sea Level
AUC	Area Under the Curve
C	City
Cl.	Climate
D	Density of the areas with habitat suitability rate of more than 0.3
DoE	Department of Environment
Dep. Var.	Dependent Variable
Dr.	Dry condition
DF	Dry Farming
Elev.	Elevation
Eq.	Equation
ENM	Ecological Niche Modeling
F	Forest
HP	Human Population
HPI	Human Poverty Index
IF	Irrigated Farming
LC	Landscape Corridor
LU/LC	Land Use and land Cover
MaxEnt	Maximum Entropy
MR	Main Road
Mnts	Mountains

MVP	Minimum Viable Population
NHA	No Hunting Area
NP	National Park
PA	Protected Area
PCA	Principle Component Analysis
r	Correlation coefficient
R	Range
ROC	Receiver Operating Characteristic
SD	Standard Deviation
SDM	Species Distribution Modeling
SF	Scattered Farm
SR	Sub-Road
Topo.	Topography
UPM	University Putra Malaysia
V	Village
Veg.	Vegetation
WR	Wildlife Refuge

CHAPTER 1

INTRODUCTION

1.1 General overview

Fragmentation of habitats into smaller patches and loss of suitable areas and connectivity of patches in landscapes pose a serious threat to populations' viability of various large predator species (Gerber *et al.*, 2012; Johnstone *et al.*, 2010; Michalski and Peres, 2005; Meffe and Carroll, 1997). Management efforts are to provide or recreate spatial, temporal, genetic and ecological connectivity between habitat patches (Lockwood *et al.*, 2006). Physical connectivity of reasonably undisturbed areas, e.g. through the wildlife corridors in which connect at least two major habitats (McEuen, 1993; Beier and Loe, 1992), facilitate dispersal of individuals between remaining patches (Cushman and Landguth; 2012; With and King, 1999). This allows for the long term genetic interchange and re-colonizing the relative areas (Bond and Lake, 2003).

As a result of fragmentation serious declines occur in the total area of habitats and they split into smaller and more isolated patches (Saunders *et al.*, 1991; Harris, 1984). While maintaining connectivity of habitat patches in increasingly populated areas even in the same political boundary is a challenge, managing such habitats in international borderlands poses as a serious issue for many countries (De Jong *et al.*, 2010; IUCN, 2007; Bennett and Mulongoy, 2006). Changes in vegetative composition of habitats and subsequently type and quality of the food base, changes in predation and competition, demographic stochastic and reduction in genetic diversity, human-predator conflicts, increasing opportunities of poaching and increasing local extinctions are among the adverse effect of habitat fragmentations (Watson, 2005; Knaepkens *et al.*, 2004; Anderson, 1999; Noss and Cooperrider, 1994).

Even though, large predators may persist for decades in fragmented habitats (Turner and Corlett, 1996), their long term viability in these areas are threatened by various factors, e.g. effect of human disturbances, edge effects and reduction in immigration rates (Dannemann *et al.*, 2018; Niebuhr *et al.*, 2015; Levins, 1969). Thus, predicting responses of various species to habitat

fragmentation, habitat loss and reduction of habitat suitability rates caused by the land use and land cover changes is a matter of concern for conservation biologists (With and King, 1999). While each case of the land cover alternation or changes in land use could occur in a small scale, but cumulative effect of these changes may perhaps produce a significant impact leading to the actual fragmentation (see also Theobald *et al.*, 1997). Thus, understanding the responses of the species to these changes allows for identification of priority areas and further effective management planning (Moilanen *et al.*, 2005).

Considering this overview, current study is an innovative attempt to formulate a species and area specific model and a threshold level to enable managers and conservationists to predict the cumulative effect of changes in land use and land cover variables on the Persian leopard (*Panthera pardus saxicolor*) regional persistence in Iran. Three research chapters are presented in this thesis in which the first one represents countrywide distribution modelling of the Persian leopard in a regional context. The second chapter concentrates on the ground validation of the developed maps in three different provinces across the country. The third research chapter uses the outcomes of first two research chapters to develop the innovative model regarding the regional persistence of the Persian leopard in Iran.

1.2 The Persian Leopard: General introduction

1.2.1 Taxonomy

Due to the variability in habitat types and conditions (see also Sunquist and Sunquist, 2002) where the Persian leopard inhabit either in Iran or elsewhere in the west, south and central Asia, morphological features and morphometric characteristics (e.g. body size measurements, coloration, coat pattern) are also variable (Khorozyan *et al.*, 2006 Kiabi *et al.*, 2002; Sanei, 2007; Etemad, 1985; Heptner and Sludsky, 1972). Therefore, considering phenotypic variations and geographic extent, scientists had described more than one leopard subspecies exist in Iran (e.g. *P.p. dathei* Zukowsky, 1959; *P. p. sindica* Pocock, 1930; *P.p. saxicolor* Pocock, 1927). However, more recent investigates including molecular genetic studies and craniometric analysis confirmed and supported the presence of one leopard subspecies in Iran, i.e. *P.p. saxicolor* (see also Farhadinia *et al.*, 2015; Rozhnov *et al.*, 2011; Khorozyan

et al., 2006; Meijaard, 2004; Ullrich and Riffel, 1993; Uphyrkina *et al*., 2001; Miththapala *et al*., 1996).

1.2.2 Distribution pattern

While the Persian leopard range in south, west and central Asia has been limited during the past decades, the subspecies is known to be widely distributed in Iran (Sanei *et al*., 2016) and still extant in Turkmenistan, Armenia, Azerbaijan, Iraq, Turkey, Afghanistan, Pakistan and Russia. However, the Persian leopard presence is uncertain in Georgia, possibly extant in Uzbekistan and possibly extinct in Tajikistan (Stein *et al*., 2016; Lukarevsky *et al*., 2007; Khorozyan *et al*., 2005).

In Iran, historical reports denoted the leopard as a common species in mountains and hills particularly along the Alborz and Zagros mountainous chains (Joslin, 1990; Misonne, 1959; Pocock, 1930; Birulya, 1912; Blanford, 1876) except for the agriculture lands and vast plains, e.g. the deserts (Harrington and Darreshuri, 1977; Lay, 1967).

However, recent countrywide studies documented the leopard presence in 74 protected and non-protected habitats out of a total of 90 investigated sites which eventually covers all provinces except for the Hamedan (Sanei and Zakaria, 2011c; Sanei, 2004, 2007). These studies suggested that 55% of leopard presence areas are protected which is well in agreement with population guesstimates by Kiabi *et al.* (2002). Subsequently, Sanei *et al.* (2016) conducted new distribution and status assessments which then hypothesized that the leopard distribution range in Iran is in the process of splitting into the northern and the southern parts.

1.2.3 Ecology and behavior of leopard

The studies concerning the leopard ecology in Iran were handful. As such, study of territorial marking of leopards in Bamu demonstrated that most of the scrapes were claw in the winter which is known to be the mating season for the leopard in the region (Ghoddousi *et al*., 2008). Other reports from Sarigol NP, North Khorasan province, indicated that the mating season was from January to February (Farhadinia *et al*., 2009). There are also numerous records of attacks of leopard in domestic dog (*Canis lupus familiaris)* meant

for feeding which was confirmed by Fadakar *et al.*, (2013) via DNA tools. However, studies of spatial ecology of the leopard in Tandureh NP, north-eastern Iran, are still on-going (Farhadinia, unpub. data).

1.2.4 Disease

On the subject of the knowledge about disease of the Persian leopard, Namroodi *et al.*, (2015) conducted a study on three leopards that died in road crashes in Golestan National Park, northern Iran to test *Toxoplasma gondii* and rabies virus infection. Even though rabies virus infection was not detected in any of them, two of the cats were infected by *T. gondii.* Subsequently, they concluded that toxoplasmosis might be a notable factor in leopard road kills. *Taxocara cati* was recorded in two other leopards (male and Female) in Golestan NP, while parasites found in the female individual was 7 times more than the male individual in the same area (Ghaemi *et al.*, 2011). *Ancylostoma tubaeforme* was recorded in a young female illegally killed in Semnan province (Youssefi *et al.*, 2010). Shistosoma spp. was recorded in one leopard faeces in Degarmanli site in Golestan NP (Persian Leopard Online Portal, unpublished records, accessed 07 August 2012). Mowlavi *et al.* (2009) detected *Trichinella britovi* in a leopard as they recovered larvae from the specimen muscles.

1.2.5 Habitat

Even though leopards are found in a variety of habitat conditions ranging from temperature of – 23.1˚ C to 49.4˚ C, they are mostly recorded in the areas with 13-18˚ C and duration of ice cover with less than 20 days/year and more than 200 mm/year of precipitation (Sanei and Zakaria, 2011c and 2008). Elevation of 1,100-1,200 m and slopes of 30-65˚ in Turan NP and PA (Mobargha, 2006) and elevation of 1,800 – 2,400 m and slopes of 20-70˚ in Kolah Ghazi NP (Omidi *et al.*, 2010) are identified as the most suitable habitats for the leopards in the above mentioned areas. Mountainous habitats, small rippling hills and rough terrain with abundant preys were found as the habitat preference for the leopard in Sarigol NP (Taghdisi *et al.*, 2013). In general, the leopard range in Iran is mostly confined to the mountainous habitats (Sanei et al., 2016). The Persian leopard is known to avoid deserts and anthropogenic landscapes, e.g. agriculture lands (Gavashelishvili and Lukarevskiy, 2008; Harrington and Darreshuri, 1977; Lay, 1967) and snow cover (Gavashelishvili and Lukarevskiy, 2008).

1.2.6 Prey

Leopard presence range is known to have 100% of conformity with wild goat *Capra aegagrus* presence in a total of 43 study sites across Iran. In the other hand, wild sheep *Ovis Orientalis,* wild boar *Sus Scrofa* and Indian crested porcupine *Hystrix indica* were found to be present in 95%, 65% and 65% of the leopard presence habitats (Sanei *et al.*, 2011). Omidi *et al.*, (2010) identified the wild goat as a main factor for leopard presence in Kolah Ghazi NP, while, in Tandureh NP, the wild goat and the wild sheep were identified as the main leopard prey (Chalani, 2005). In Golestan NP, the wild boar together with the wild sheep and the wild goat has a main part in leopard diet (Sherbafi, 2010). Attacks on domestic dogs have been frequently recorded. For instance, an old male leopard was frequently recorded to feed on domestic dogs in a village namely Tazeh Ghaleah in northeastern Iran, close to Turkmenistan border (pers. Observ.). Such records have been made in Golestan NP using sequencing the control region of mtDNA (Fadakar *et al.*, 2013). In Sarigol NP, wild sheep followed by the wild boar and wild goat were identified as the main prey for the leopard (Taghdisi *et al.*, 2013).

1.2.7 Main threats, mortality rate and human-leopard conflicts

Habitat destruction, degradation and fragmentation are reported as the main factors threatening leopard population in the national (Sanei *et al.*, 2016; Sanei and Zakaria, 2011d) and local scale (e.g. Erfanian *et al.*, 2013; Ghoddousi *et al.*, 2010 and 2008; Sanei, 2007). A total of 71 leopard mortality have been recorded from 2007 to 2011 in which 70% (n=50) of them were as a result of intentional hunting and poisoning and 18% (n=13) because of road accidents (Sanei *et al.*, 2012). In general, least number of mortality cases have been officially recorded in Iran from 2007 to 2015 includes 152 cases while 19 additional cases are not confirmed (Sanei *et al.*, 2015). Depredation on wide range of livestock mostly including domestic sheep and goat (n=7,090) and to a lesser extent camel, cow, donkey, horse and mule (n=208 kills) have been recorded. Attacks on herding dogs are also very frequent (Sanei *et al.*, 2016). Dry condition, serious prey reduction, presence of animal husbandry and livestock in leopard habitats, low ecological awareness, aftermath of Iraq and Iran war (Sanei *et al.*, 2016; Sanei and Zakaria, 2011d) and possibly presence of landmines in trans-boundary leopard areas in the neighboring Caucasus habitats (see also WWF, 2016).

1.2.8 Importance in the Iranian culture and literature

Formerly, a total of 3 members of the genus *Panthera* inhabited in Iran. These were including the Persian lion (*Panthera leo persica*), the Caspian tiger (*Panthera tigris virgata*) and the Persian leopard (*Panthera pardus saxicolor*). However, after extinction of the lion and the tiger (about 150 and 58 years ago, accordingly; Ziaie, 2008; Firouz, 2000), the Persian leopard has been the last remaining of *Panthera* species in Iran. Thus it has a unique importance for both ecological health of natural ecosystems as well as the cultural heritage in this country.

In general, the big cats (i.e. lion, tiger and leopard) have a great influence in the Iranian literature and symbolization. For instance, since 1846 until Iran revolution in 1979, lion and the sun were the elements of the Iran's national flag. In the literature works of various Persian authors the lion, the tiger and the leopard are denoted as symbols of strength, intelligence, bravery, justice and valour. As such, poems by Ferdowsi (940–1020 CE) in the Persian epic of the kings (or Shahnameh) and Sepehri (1928 – 1980) in the modern Persian poetry, are denoted.

A famous legendary of Iran namely Rostam who is a hero in Shahnameh (epic of the kings), used to wear a kind of suit made of the leopard skin (namely Palangineh) in the battles. After his death, the suit was handed to Faramarz, his son (see also Ferdowsi, 2006). According to a folktale about the leopard and the moon, a leopard may not tolerate anything overhead. In the full moon nights, tragedy happens when the leopard tries to reach to the moon from peak of the mountain. The leopard broken pride and its injured body over the sharp cliffs after clawing at the moon with no success, vanishes the desire to reach to the moon (see also moon and the leopard by Hossein Monzavi, 1946–2003).

Among other art works, the paintings remained from 8th century Iranian kings are shown with clothes made of a leopard coat which denotes strength and bravery of the kings. Yet, some elements in the Iranian carpets are influenced by the leopard and lion symbols and signs (Hermidas, 2011). All these facts indicate that large cats and in particular the leopard which has a vast distribution in the country, had a great influence on local communities during the centuries. Yet, the leopard is recognized as the king of the mountains by Iranians (Zakaria and Sanei, 2011). However, aside from the

historical significance of the large cats in arts, beliefs and thoughts of local communities and Iranians in general, there are various other factors affecting the actual interactions of the leopards and local communities in the current situation.

1.2.9 Protection status, law and regulations

The Persian leopard is listed as Endangered EN C2a (i) on the IUCN (International Union for Conservation of Nature) Red List of Threatened Species (IUCN, 2016). Endangered is defined as a species that is encountering a very high risk of extinction in the near future in the wild. Category C2a refers to the population estimate of less than 2,500 mature individuals and continuous decline in the number of mature individuals and severe fragmentation in population structure while no subpopulation is estimated to have more than 250 mature individuals (IUCN version 2.3 Categories and Criteria, 1994).

In CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), Persian leopard is listed in Appendix I which refers to the regulation that international trade of the species is prohibited. In the exceptional and non-commercial circumstances, e.g. scientific researches, translocation of an individual or any part of a specimen (e.g. bone, claw, teeth) is subjected to the import and export permissions from both originating and destination countries (CITES, 2012).

In the Iranian environmental conservation laws and regulations, the Persian leopard has been protected by national wildlife conservation law since 1999. The principal safety zones for leopards include national parks (NP); wildlife refuges (WR) and protected areas (PA) as well as no-hunting areas (NHA) with short-term protection for the purpose of enabling wildlife species to recover. Yet, some different kind of habitat protections (e.g. forest reserves) is executed by the Iranian forest, range and watershed management organization. These areas occasionally act as safety zones for the leopard and their prey species (see also forests and natural resources protection law enacted in January, 1942).

In early 2016, the Persian leopard national conservation and management plan (Sanei, 2016) were finalized and endorsed by the head of the Department of Environment (DoE) of Iran. An innovative model was developed for the planning procedure to actually address extreme diversity of natural and cultural conditions as well as economic and other relative factors that eventually affect the species conservation and management (Figure 1.1). The plan includes total of 11 main chapters which has been enacted for duration of 5 years in the first phase of implementation. These chapters include:

1. Awareness raising, training and empowerment
2. Habitat
3. Media
4. Veterinary and disease
5. Rehabilitation centers
6. Trans-boundary habitats and international cooperation
7. Genetic conservation
8. Compensation and the innovative Persian leopard insurance program
9. Persian leopard national network
10. Research, evaluation and monitoring
11. Protection units and wildlife wardens

Accordingly, the Persian leopard national insurance program has been implemented partially since early 2016 to address both compensation of livestock losses and reduction in livestock-leopard conflicts. This program also includes depredations by wolf *Canis lupus* to further improve effectiveness of the plan (see also Sanei *et al.*, 2016). Relatively, amount of the penalty for each illegally hunted leopard has been upgraded from 50,000,000 Rials equivalents to 2,014.75 USD in 2014 to 800,000,000 Rials equivalent to 26,270.30 USD in 2015.

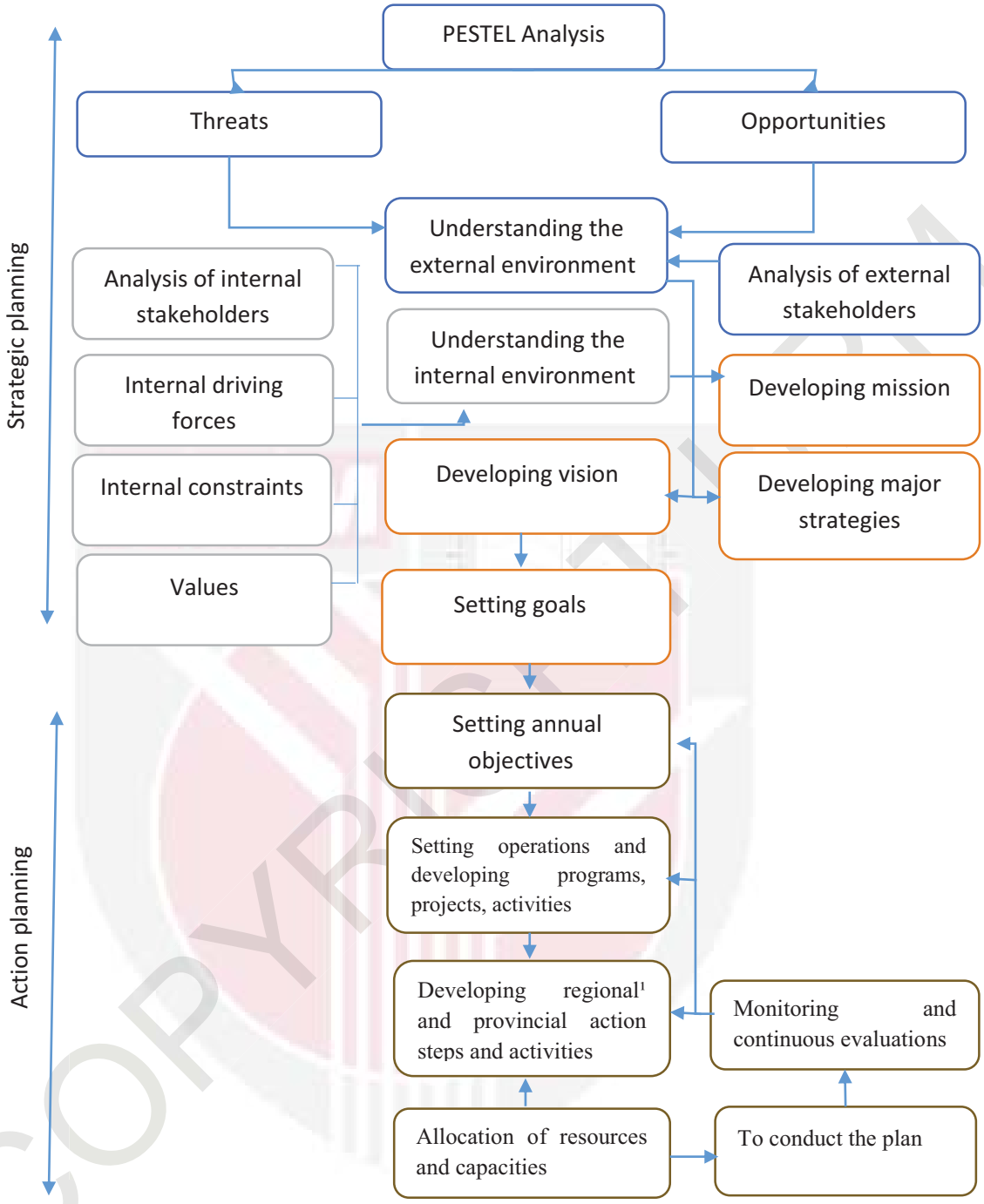

Figure 1.1 : An innovative model developed for action planning concerning conservation and management of the Persian leopard in Iran. The chart presented here, is according to the Persian leopard national conservation and management action plan in Iran.
(Sanei, 2016)

1.3 Problem statement

Various species and in particular, the territorial big cats, are vulnerable to habitat loss and fragmentation. Understanding the distribution and habitat requirements of the species together with the population estimates and the trends over time are the key parameters required for designing suitable management strategies and prioritization in allocation of the limited resources (Richmond-Coggan, 2006; Karanth, 2003; Nowell and Jackson, 1996). While developments and disappearance of vast areas of habitats particularly in developing countries is considered as a main threat to the large felids (Sanei and Zakaria, 2011a, b; Nowell *et al.*, 2007; Sunquist and Sunquist, 2001; Anderson, 1999), adequate knowledge about the key areas and a threshold level for various anthropogenic factors is essential for establishing the conservation priorities (Ariyanto, 2015; Ario, 2007; Lindenmayer and Fischer, 2006). Relatively, a possibility that the leopard distribution in Iran is in the process of splitting into a northern and the southern parts has been hypothesized in a recent study (Sanei *et al.*, 2016). This is a main concern not only for the leopard persistence in Iran, but also its presence in the neighbouring countries where the species occurrence is supported by trans-boundary movements. Thus, identification of the leopard habitats, habitat arrangements and suitability rates are the main concern for the Persian leopard conservation in Iran.

Aside from the influence of each single variable of land use (LU) and land cover (LC) and identification of the particular threat factors, no study has been done so far to assess the cumulative effect of multiple drivers of changes on the persistence of the Persian leopard in either regional or countrywide and even local scales. On the other hand, preventing the development activities across the entire country due to the wide distribution of the Persian leopard in Iran is not realistic and feasible. Yet, being a top predator as well as an umbrella species, assessing a research-based species and region specific conservation program, eventually influence conservation status of a large number of other species (e.g. brown bear, grey wolf, striped hyena, roe deer, red deer, etc.) and wide range of habitats. Yet, influencing the programs for LU/LC changes and development activities to eventually ensure existence of the adequate amount of suitable areas with enough suitability rates and proper arrangements and connectivity among them, is particularly an urgent need for leopard conservation in Iran. This would not be possible without influencing the development strategies and drawing attention of decision takers and land use managers to the research based

solutions for nature friendly development activities. Yet, politicians' considerations about cost effective practical solutions should be noted.

Thus, identification of the habitats, their suitability rates and significance of each area in relation to the probability of leopard presence and arrangements of the other habitats in the region and assessing the cumulative influence of LU/LC variations on the local and regional leopard persistence are essentially required. Assessing regional models that explain how the changes of each single LU/LC variable is actually affecting leopard persistence in local, regional and eventually, countrywide scales in relation to the other factors in the area, is the current innovative practice dedicated to the Persian leopard conservation and management in Iran. This model enables the managers and decision takers to adjust and combine the development activities and conservation efforts in the best possible way to ensure that present status of the LU/LC is not harming the leopard persistence, followed by numerous other coexisted species, in a wide scale.

1.4 Justification and significance of the study

The range of the Persian leopard in south west Asia has been seriously restricted during the past decades (see also Sanei *et al.*, 2016; Khorozyan and Abramov, 2007; Versechagin, 1959). However, land use and land cover changes across the leopard range (Sanei and Zakaria, 2011c) resulted from human factors and natural mischances (see also Mirzaei *et al.*, 2015; Sanei and Zakaria, 2011d; Asgari *et al.*, 2008) are increasingly threatening the main population of this subspecies in Iran (see also Stein *et al.*, 2016; Kiabi *et al.*, 2002). As such, understanding the current status of this main population together with conservation requirements particularly in terms of habitat availability and connectivity while land use and land cover changes increasingly occur (e.g. Azizi and Jafari, 2016; Rezaei *et al.*, 2016; Mirzaei *et al.*, 2015), is essential.

Obtaining reliable population estimates and demographic trends for secretive, nocturnal and solitary leopards (Sergeant *et al.*, 2003; Eltringham, 1979) with the range dispersal across 30 provinces of Iran (Sanei et al., 2016; Sanei and Zakaria, 2011c), is problematic (Vold and Buffett, 2008) due to the time, financial and human resources constraints. Thus, studies concerned with population trends and demographic data such as death and birth rates (e.g. for Population Viability Analysis, Lindenmayer *et al.*, 1993) are

problematic. However, study on the distribution patterns and relative parameters in a large scale are practically feasible and provides a reliable basis to understand the species status and dynamics over time. Previous studies demonstrated that habitat loss and fragmentation negatively influences species persistence (see also Roques and Stocia, 2007), thus, habitat suitability rate is connected to the species persistence in a region.

Relatively, models related to the land use and land cover changes have extensive variety depending on data availability, modelling goals and methodological approaches (Brown *et al.*, 2014). These models are generally used to predict the changes of land use and land cover in future or evaluate various scenarios which are also very helpful in decision making and conservation programs (Sanchez and Alonso, 2008; Turner *et al.*, 2004; Singh, 2003; Agarwal *et al.*, 2002).

However, no study is conducted so far to assess cumulative effect of land use and land cover changes on the Persian leopard. Due to the absence of such researches and an urgent need to provide research-based data for conservation practices via influencing rapid development strategies in and around leopard natural habitats, this study was carried out to develop an innovative model to further improve the Persian leopard conservation practices.

Typically, LU/LC change models investigate the relationship between the variables and historical land transitions. Afterwards, these relationships will be used for building models about land transitions in the future (Ahmed *et al*., 2013). In general, land use and/or land cover change models have been classified into various categories such as economic (divided to non-spatial explicit and spatial explicit models) and non-economic models (Irwin and Geoghegan, 2001), empirically fitted and process simulation models (Brown *et al*., 2004), land cover in distributional models (changes in proportion of a landscape) and spatial landscape models (location and configuration of changes; Baker, 1989), also to empirical and statistical, mathematical, spatial simulation models (Lambin, 1997). Among these categories, empirically fitted models are about description of the process on the basis of measured data during that process in specific place and time. However, process simulation is according to a general understanding about the processes and simulating the outcomes via building models in specific places (Brown *et al*., 2004).

Accordingly, to develop empirically fitted models on the basis of the actual data for the purpose of this research, assessing the leopard potential habitats with relative suitability rates, validation of such models on the ground and relative corrections, also selection of LU/LC variables affecting habitat suitability rates together with the relative threshold level are essential. Yet, concerning notable variation of environmental factors in various provinces of Iran, identification of significantly dissimilar regions to develop regional models was considered. Thus, aside from producing the regional habitat suitability distribution maps which eventually cover the entire country, cumulative effects of LU/LC variables was also modelled on the regional basis.

1.5 Thesis statement

A major contribution of this thesis to conservation and management of the Persian leopard in Iran is formulating a predictive model and assessing the relative threshold level to address the cumulative effect of LU/LC variations on regional persistence of the Persian leopard in relation to the habitat suitability rates. However, a research question in this thesis is about the possibility that the Persian leopard potential habitats in Iran are in the process of a major fragmentation that may split the entire potential range into northern and southern parts. This question has been hypothesized by previous studies after plotting the recent presence locality of the Persian leopards in Iran (Sanei *et al.*, 2016). Relatively, modelling of the leopard potential habitat distribution across the entire country is conducted in which existence of landscape corridor/s to improve the connectivity in the metapopulation scale is studied.

In this regards, definition of key terms and assumptions are clarified in chapter 3. The overall study design is considered in a regional context to address the regional variability of environmental factors in various provinces of Iran. Thus, each region is consisted of several provinces which are found to be significantly similar in terms of the selected environmental and human factors.

In general, land cover is defined as biophysical status of the land surface and the immediate sub-surface. While land cover changes are related to either human or natural factors, the purpose of land use is generally associated with nature of the land cover. Therefore, understanding the changes in land

use is necessary to understand the changes in land cover and vice versa (Anwar, 2014).

Regional species potential distribution models are developed using MaxEnt software version 3.3.3K to assess the potential habitats for the leopard. A potential habitat in these models is considered as a habitat with some degree of suitability for the leopard persistence. This leads to the potential distribution map of the species that indicates the distribution pattern of the suitable habitats for leopard persistence. Probability of suitability is estimated by the software using environmental variables and presence records. MaxEnt also provides the permutation importance for each variable which is the measure of contribution of variables by permuting their values randomly among both species presence and environmental background training points and assessing resulting reduction in training AUC. Despite of the percentage contribution which is calculated on the basis of tracking the variables during the modelling process, then, converting the result to percentage, permutation importance is not dependent on the path that MaxEnt used to obtain the final model (Phillips, 2006).

A landscape corridor is a cluster of connecting habitats that provides opportunity for movements of individuals of the species between various areas (IUCN, 2007). This study also investigated the landscape corridors in a metapopulation scale which is consisted of connecting local populations where individuals uncommonly move from one to another across the habitats which are unsuitable for feeding and breeding (see also Nouhuys, 2016; Hanski and Gilpin, 1991). With this definition, habitat fragmentation occurs when habitats break off into the isolated patches due to the reduction of the areas of habitats (Saunders *et al.*, 1991; Harris, 1984).

1.6 Objectives

The general objective for this thesis is to formulate a model to predict regional persistence of the Persian leopard on the basis of the current potential range and cumulative effect of changes in selected land use and land cover variables. There are six specific objectives that are addressed in one of the three research chapters:

1. To estimate potential distribution of the Persian leopard in Iran considering the extensive variability of the environmental condition (chapter 4)
2. To predict landscape corridor/s to improve distribution pattern connectivity in a metapopulation scale (chapter 4)
3. To identify the main environmental factors contributing to assess the leopard potential distribution in Iran (chapter 4)
4. To validate the best fitted leopard distribution models on the ground in selected study areas in order to assess a threshold value indicating the minimum suitability rate that can be safely used in further conservation practices (chapter 5)
5. To develop a species and region specific model for assessing cumulative effects of *priori* selected land use/land cover variables on the regional persistence of the Persian leopard with respect to the habitat suitability rates (chapter 6)
6. To propose a species specific threshold level for land use and land cover variations affecting habitat suitability rates with influence on the regional leopard persistence in Iran (chapter 6)

1.7 Hypothesis

One null hypothesis is generated for the current thesis in which is stated as follows. It should be noted that the MaxEnt investigated another null hypothesis saying that the test points prepared for the model validation are predicted no better than a random prediction. This is addressed in chapter 4.

H0: Permutation importance of the research environmental variables in the best fitted MaxEnt models does not significantly vary according to the regional differences of the environmental variables (chapter 4)

1.8 Organization of the thesis

This thesis is organized in a total of 7 chapters including three research chapters:

Chapter 1. This chapter includes a general overview to the species concerning taxonomy, distribution, ecology and behaviour, habitats, preys, main threats, mortality rates and conflicts, cultural significance and conservation laws and regulations. This chapter also illustrates the main research problems and relative justifications together with research question, main and specific objectives and the hypothesis.

Chapter 2. Second chapter is dedicated to the review of literature in three main sections of ecological concepts related to the research topic, statistical aspects of the methodologies used in this research as well as a review to the land use / land cover changes modelling. Ecological aspects reviewed in this chapter includes subjects about population viability, minimum viable population and extinction risk, also niche concept and Hutchinson's biotope-niche duality, ecological niche modelling and species distribution. Statistical reviews include Maximum Entropy, Principle Component Analysis and the curvilinear regression. A brief review is also presented to the status of the Persian leopard in South-West Asia while more details about introduction to the sub-species in Iran is provided in the first chapter.

Chapter 3. There are three research sections in which each of them includes a standalone research topic, but also the results and findings of each is much related to the others. Thus chapter 3 is dedicated to a general overview to the methodologies used in these sections. This chapter includes the conceptual frame work of the thesis as well as the definition to the key terms and assumptions.

Chapter 4, 5 and 6. These chapters include separate research topics that eventually the findings are related to each other. Classification of regions is illustrated in chapter 4. Each research chapter include its own objectives, methodologies, results and discussions. The null hypothesis is addressed in chapter 4.

Chapter 7. The last chapter includes conservation implications and relative recommendations along with the final conclusion of the thesis.

References. The references cited in the thesis, are indicated in this section.

Appendices. All materials mentioned in the text as appendix are presented in appendices.

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