Multi–criteria evaluation and simulated annealing for delimiting high priority habitats of *Alectoris chukar* and *Phasianus colchicus* in Iran

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Momeni Dehaghi, I., Salmanmahiny, A., Karimi, S., Shabani, A. A., 2018. Multi–criteria evaluation and simulated annealing for delimiting high priority habitats of *Alectoris chukar* and *Phasianus colchicus* in Iran. *Animal Biodiversity and Conservation*, 41.1: 185–193, Doi: https://doi.org/10.32800/abc.2018.41.0185

Abstract

Multi–criteria evaluation and simulated annealing for delimiting high priority habitats of Alectoris chukar *and* Phasianus colchicus *in Iran.* Habitat degradation and hunting are among the most important causes of population decline for *Alectoris chukar* and *Phasianus colchicus*, two of the most threatened game species in the Golestan Province of Iran. Limited data on distribution and location of high–quality habitats for the two species make conservation efforts more difficult in the province. We used multi–criteria evaluation (MCE) as a coarse–filter approach to refine the general distribution areas into habitat suitability maps for the species. We then used these maps as input to simulated annealing as a heuristic algorithm through Marxan in order to prioritize areas for conservation of the two species. To find the optimal solution, we tested various boundary length modifier (BLM) values in the simulated annealing process. Our results showed that the MCE approach was useful to refine general habitat maps. Assessment of the selected reserves confirmed the suitability of the selected areas (mainly neighboring the current reserves) making their management easier and more feasible. The total area of the selected reserves was about 476 km^2. As current reserves of the Golestan Province represent only 23 % of the optimal area, further protected areas should be considered to efficiently conserve these two species.

Key words: Common pheasant, Chukar partridge, Conservation planning, Habitat suitability, Multi–criteria evaluation, Marxan, Simulated annealing

Resumen

Evaluación de múltiples criterios y recocido simulado para delimitar los hábitats de alta prioridad de Alectoris chukar *y* Phasianus colchicus *en Irán.* La degradación del hábitat y la caza son algunas de las causas más importantes del descenso demográfico de *Alectoris chukar* y *Phasianus colchicus*, que son dos de las especies cinegéticas más amenazadas de la provincia de Golestán del Irán. La escasez de datos relativos a la distribución y localización de hábitats de alta calidad para las dos especies dificulta las iniciativas de conservación en la provincia. Utilizamos la evaluación de múltiples criterios para hacer una primera selección de las zonas de distribución general y elaborar mapas de idoneidad de los hábitats para las especies. A continuación, utilizamos estos mapas en forma de algoritmo heurístico en el recocido simulado por medio del programa informático Marxan, a fin de establecer un orden de prioridad entre las zonas para la conservación de ambas especies. Para hallar la solución óptima, probamos varios valores del modificador de longitud de frontera en el proceso de recocido simulado. Nuestros resultados pusieron de manifiesto que la evaluación de múltiples criterios resultó útil para refinar los mapas de hábitat general. La evaluación de las reservas seleccionadas confirmó la idoneidad de las zonas seleccionadas (que principalmente son contiguas a las reservas actuales) lo que facilita su gestión y la hace más viable. La superficie total de las reservas seleccionadas fue de unos 476 km^2. Como las reservas actuales de la provincia de Golestán solo representan el 23 % de la superficie óptima, deberá estudiarse la posibilidad de añadir otras áreas protegidas a efectos de conservar de forma eficiente estas dos especies.

ISSN: 1578–665 X
eISSN: 2014–928 X

Palabras clave: Faisán común, Perdiz chucar, Planificación de la conservación, Sostenibilidad del hábitat, *Evaluación de múltiples criterios, Marxan, Recocido simulado*

Received: 8 XII 14; Conditional acceptance: 10 II 15; Final acceptance: 9 IX 17

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Introduction

Based on the *International Union for Conservation of Nature and Natural Resources (*IUCN) Red List of Threatened Species, around 13 % of all known bird species worldwide are under threat (IUCN, 2014). In addition, some species are exposed to threats and are undergoing rapid population declines locally, but their global status is ranked as Least Concern (LC) in the IUCN Red List (Mansoori, 2008). This is especially true for game species in developing countries. The common pheasant (*Phasianus colchicus*) and chukar partridge (*Alectoris chukar*) are considered galliform species of special concern according to their ecological and economic importance in the Golestan Province of Iran (Salmanmahiny, 2008). While the common pheasant prefers forests and shrublands in humid climates, the chukar partridge prefers mountainous, rocky habitats and avoids dense–forests (Mansoori, 2008). Inability to fly long distances makes these species vulnerable to hunting. Habitat degradation caused by land–use/land–cover change (Minaei and Kainz, 2016) and hunting (Panayides et al., 2011) are among the most important causes of population decline for these species and they require considerable conservation efforts in Iran (Mansoori, 2008).

Knowledge about species' habitats and distribution is fundamental for conservation efforts (Lawler et al., 2011; Underwood et al., 2009). However, in general, there is a lack of high–quality data about species distributions (Store and Kangas, 2001; Store and Jokimäki, 2003), especially in developing countries such as Iran (Momeni et al., 2013). Habitat suitability modeling as a surrogate of distribution data can be used to fill this gap in conservation studies (Store and Kangas, 2001; Store and Jokimäki, 2003; Lawler et al., 2011). MAXENT (Phillips et al., 2006), ENFA (Hirzel et al., 2002) and GAMs (Hastie and Tibshirani, 1986) are among the most popular models used to provide habitat suitability maps. However, these methods need accurate occurrence data of species and very often such data are not available. Multi–criteria evaluation (MCE) is a good, first step towards achieving refined information about species suitability maps (Store and Kangas, 2001; Store and Jokimäki, 2003). With the MCE method, the environmental variables deemed relevant and important are combined according to their relative weight for the species under study (Momeni, 2011). Habitats with the highest suitability are then singled out, showing the most probable points of a species' occurrence. This information can be fed into the methods requiring accurate presence data.

Establishing reserve networks is an important and effective tool for conserving high–quality habitats and biodiversity (Possingham et al., 2006; Ceballos, 2007; Lawler et al., 2011). Systematic approaches to reserve selection are preferred to *ad hoc* approaches because the former are data driven, goal directed, efficient, explicit, transparent, repeatable and flexible (Pressey, 1999). A wide array of systematic conservation tools and algorithms has been developed to assist the reserve selection process (Lawler et al., 2011). Simulated annealing (SA) as a heuristic algorithm inspired from annealing in metallurgy (Kirkpatrick et al., 1983) has been developed for purposes of optimization and spatial configuration (Aerts and Heuvelink 2002; Pressey, 2002) considering a 'minimum set problem' (McDonnell et al., 2002, Game and Grantham, 2008). SA is subject to iterative improvement, although it accepts bad moves randomly to prevent getting trapped in local minimum solutions (Ardron et al., 2010). The SA algorithm has been successfully used in conservation planning and reserve selection around the world (Airame et al., 2003; Andelman and Willig, 2002; Hermoso et al., 2010; Leslie et al., 2003). Its applicability was recently also tested in Iran (Mehri et al., 2014; Momeni et al., 2013).

The main goal of this study was to prioritize habitats of two galliform species (*Alectoris chukar* and *Phasianus colchicus*) in Golestan Province and to introduce these areas as possible, new reserves to protect the declining populations of these species. We loosely linked the MCE approach and the SA algorithm within Marxan software (Ball and Possingham, 2000) to find the optimum network of habitats for conservation. The optimum solution in our research was defined as the selection of a conservation network with a minimum area that could meet the conservation targets of the species. Finding the optimum network is important in developing countries because of chronic shortages in funds for conservation efforts.

Material and methods

Study area

Golestan Province is located in north east Iran (fig. 1). It has a total area of 20,430 km^2 and diverse climatic and ecological conditions. The province is one of the richest areas in Iran in terms of biodiversity. Golestan National Park, Khoshyeylagh Wildlife Sanctuary, Jahannama, Loveh, and Zav protected areas constitute the reserve networks of the Golestan Province. However, all these reserves were selected on an ad hoc basis and do not necessarily encompass the most important areas for the protection of biodiversity (Momeni et al., 2013). The Golestan Province has three different climates: plain moderate, mountainous, and semi–arid. The average annual temperature is around 18º Celsius and the annual rainfall is around 550 mm (Malekinezhad and Zare–Garizi, 2014). The altitude in the study area varies between –15 m (in the vicinity of the Caspian Sea) and 3,363 m (Alborz mountains). The Hyrcanian forests and urban areas cover 17.5 and one percent of the study area, respectively.

Habitat suitability

We selected high priority habitats of *Alectoris chukar* and *Phasianus colchicus* in Golestan Province. As a first step, we developed habitat suitability maps for the species under study using the MCE method (Eq. 1) and the general species distribution data in the form of

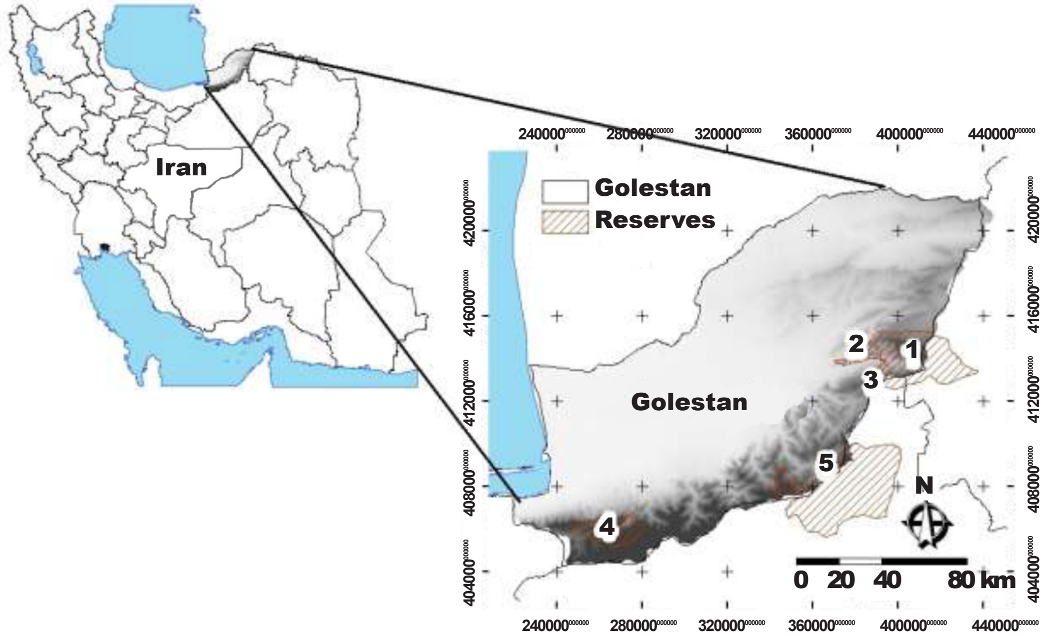

Fig. 1. Location of Golestan Province (study area) in Iran: 1, Golestan National Park; 2, Zav Protected Area; 3, Loveh Protected Area; 4, Jahannama Protected Area; 5, KhoshYeylagh Wildlife Sanctuary.

Fig. 1. Localización de la provincia de Golestán (zona de estudio) en Irán: 1, Parque Nacional de Golestán; 2, área protegida de Zav; 3, área protegida de Loveh; 4, área protegida de Jahannama; 5, refugio de vida silvestre de KhoshYeylagh.

polygons. Store and Kangas (2001) suggested using this method for areas with a lack of suitable data. These polygons had been drawn by wildlife wardens on general maps and used as guides to select the most appropriate environmental variables for habitat mapping. The species habitat requirements were specified using nominal habitat suitability models provided by Salmanmahiny (2008) (table 1). Altitude (METI and NASA, 2011), vegetation cover (DiMiceli et al., 2011), edge and interior diversity (neighborhood analysis of land–use), climatic variables (Hijmans et al., 2005) and distance to roads, rivers, and settlements (NCC, 2005) were used in this connection. Pairwise–correlation tests were applied to single out the uncorrelated parameters ($r < 0.8$). These information layers were studied inside and outside the general distribution polygons delimited by wildlife wardens, along with resorting to scientific documents on the species' habitat requirements (Mansoori, 2008; Salmanmahiny, 2008). This helped to define ranges for the selected factors reported in table 1. As habitat factors do not have the same importance for each species, weighting is necessary. We used the Analytic Hierarchy Process (AHP) for factor weights and applied the combination using equation 1

$$S = \Sigma_{i = 1 \text{ to } n} W_i X_i \qquad \text{(Eq. 1)}$$

where S is suitability, W_i, weight of the environmental variable i and X_i, value of environmental variable i.

Habitat suitability maps provided in step 1 were standardized in the range of 0 to 255 (figs. 2A, 2C), a common range in fuzzy calculations. We next used experts' opinions to define a threshold limit for re–classification of the produced habitat suitability layers. We chose areas with values higher than 150 and a minimum size of 0.1 km^2 (10 hectares) as suitable habitats (value = 1), and areas with values less than 150 as unsuitable habitats (value = 0) (figs. 2B, 2D). We defined a minimum area of 0.1 km^2 because management of the small habitat patches was not feasible.

Finally, to assess the accuracy of the habitat suitability models of the species, we calculated partial AUC (pAUC) models using few occurrences data (seven points for the Chukar Partridge and five points for the Common Pheasant) gathered by wildlife wardens. Calculations were made in Niche Analysts 3.0 software (Qiao et al., 2016).

Reserve selection

Binary habitat layers were fed into the Marxan software. Marxan is the most widely used and global leader of conservation planning software and has been used in approximately 184 countries for the selection of nature reserves (http://marxan.net). This software allows users to find the minimum number of sites needed to represent all conservation targets

Table 1. Habitat requirements of *Alectoris chukar* (Ac) and *Phasianus colchicus* (Pc) and their relative weights (W) in the Golstan Province (Salmanmahiny, 2008): temp, temperature.

Tabla 1. Requisitos del hábitat de Alectoris chukar *y* Phasianus colchicus *y su peso relativo en la provincia de Golestán (Salmanmahiny, 2008): temp, temperatura.*

Environmental variable	Ac	W	Pc	W	Weights source
Elevation (m)	0–3,500	0.02	0–2,500	0.02	DEM (METI, NASA, 2011)
Tree cover (%)	0–20	0.10	0–39	0.16	MODIS (DiMiceli et al. 2011)
Herbal cover (%)	3–99	0.07	34–100	0.06	MODIS (DiMiceli et al. 2011)
Bare land (%)	0–80	0.10	0–50	0.09	MODIS (DiMiceli et al. 2011)
Edge diversity (Unitless)	1–42	0.13	1–42	0.17	Land–use
Interior diversity (Unitless)	1 to 6	0.13	2–6	0.17	Land–use
Minimum temp in coldest month (ºC)	–15–1.2	0.02	–11.1–6.3	0.02	WorldClim (Hijmans et al., 2005)
Annual temp range (ºC)	34–42	0.02	–	–	WorldClim (Hijmans et al., 2005)
Annual mean temp (ºC)	–	–	8.3–19.4	0.05	WorldClim (Hijmans et al., 2005)
Mean temp in wettest season (ºC)	–	–	5.7–15.9	0.01	WorldClim (Hijmans et al., 2005)
Mean temp in driest season (ºC)	–	–	19 to 28.2	0.01	WorldClim (Hijmans et al., 2005)
Mean temp in coldest season (ºC)	–5–7	0.02	–4.3–11.6	0.01	WorldClim (Hijmans et al., 2005)
Mean temp in warmest season (ºC)	–	–	20–30	0.01	WorldClim (Hijmans et al., 2005)
Annual precipitation (mm)	167–264	0.01	–	–	WorldClim (Hijmans et al., 2005)
Precipitation in wettest season (mm)	84–125	0.01	–	–	WorldClim (Hijmans et al., 2005)
Precipitation in driest season (mm)	10–21	0.01	–	–	WorldClim (Hijmans et al., 2005)
Precipitation in warmest season (mm)	10–27	0.01	–	–	WorldClim (Hijmans et al., 2005)
Precipitation in coldest season (mm)	47–99	0.01	–	–	WorldClim (Hijmans et al., 2005)
Distance to roads (m)	150–27,000	0.05	89–12,000	0.05	1: 25,000 topography map (NCC, 2005)
Distance to rivers (m)	> 16,000	0.09	< 12,000	0.09	1: 25,000 topography map (NCC, 2005)
Distance to human settlement (m)	> 1,000	0.20	> 500	0.08	1: 25,000 topography map (NCC, 2005)

(Ardron et al., 2010). The simulated annealing in the Marxan requires definition and selection of planning units, conservation targets, boundary length, and objective function.

Planning units (PUs) are parts or parcels of land that Marxan works on during selection of the desired reserves. PUs must cover all parts of the study area and their size should be appropriate in terms of the species being considered for conservation and the size of the final reserves (Game and Grantham, 2008). Hexagons, watersheds, and grids are common PUs (Game and Grantham, 2008). The study area was partitioned into 20,430 hexagon planning units with a minimum area of 1 km^2 (100 hectares), relatively the same number and area as that used in Heller et al. (2015).

Targets are the quantitative values of each conservation feature to be achieved in the final reserve solution (Game and Grantham, 2008). We used a target of 20 %, meaning that the final reserves selected should contain at least 20 % of the total area of each species' habitats. We used 50 repeat runs and 10,000,000 iterations for Marxan.

Boundary length modifier (BLM) is a multiplier that determines the importance of boundary length relative to the cost of the reserve. Normally, a trial and error approach is used to find an appropriate BLM value (Game and Grantham, 2008). We examined a range of BLM values (0 to 60) to select the optimum configuration of the selected habitats.

The objective function used in Marxan (Eq. 2) is designed to minimize the total cost of the selected areas (Ball and Possingham, 2000).

$$\sum \text{Cost} + \text{BLM} \sum \text{Boundary} + \\ + \sum \text{SPF} \times \text{Penalty} + \text{Cost Threshold Penalty} \quad \text{(Eq. 2)}$$

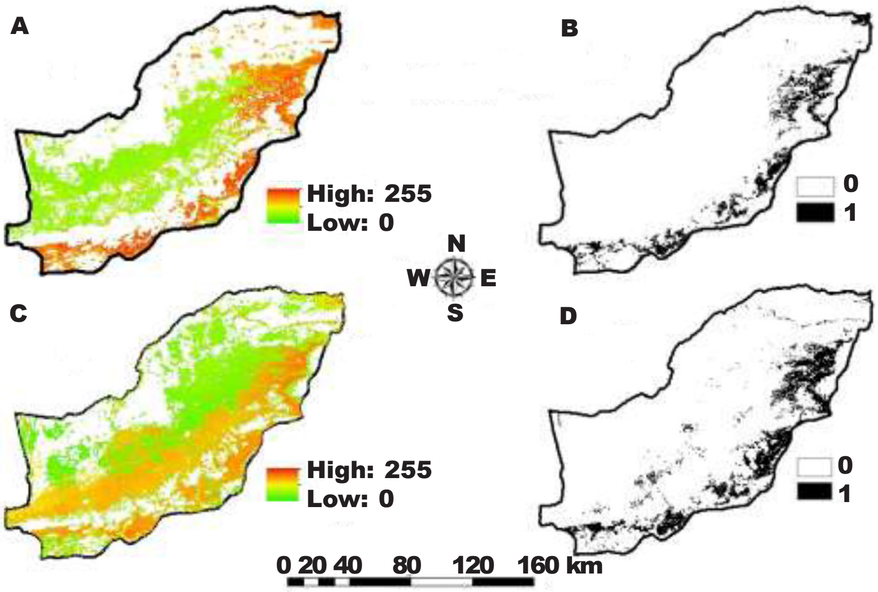

Fig. 2. Habitat suitability and Boolean maps for *Alectoris chukar* (A and B) and *Phasianus colchicus* (C and D).

Fig. 2. Idoneidad del hábitat y mapas booleanos para Alectoris chukar *(A y B) y* Phasianus colchicus *(C y D).*

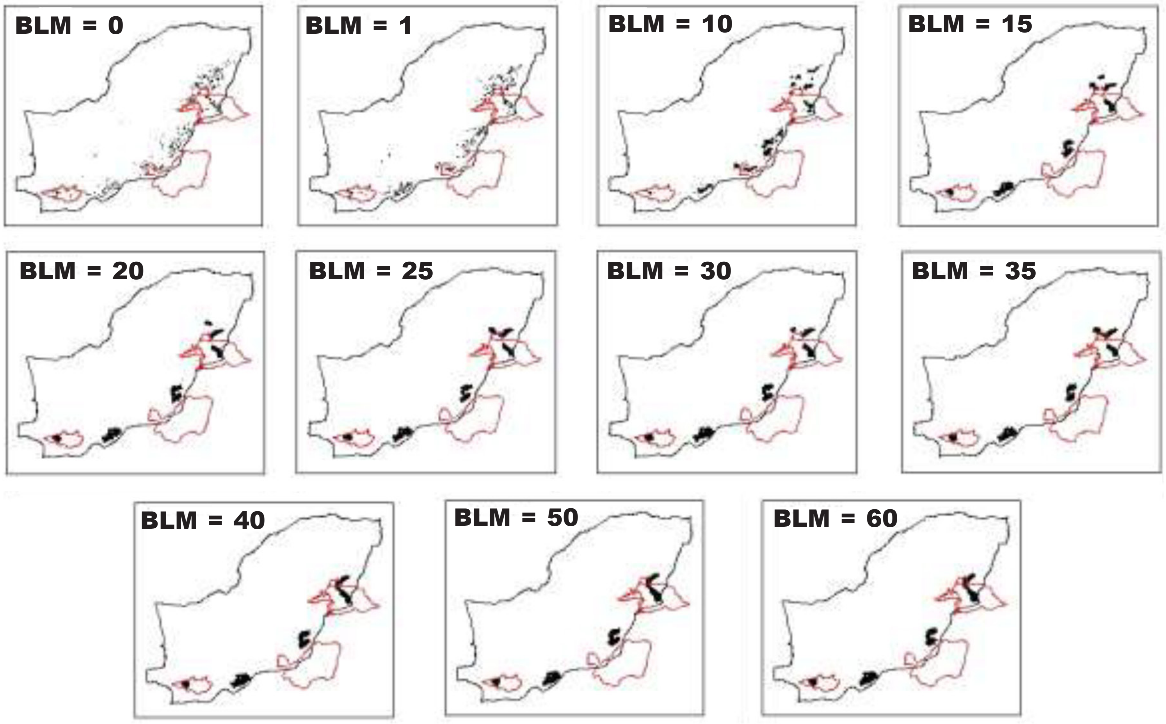

Fig. 3. Selected reserves using different BLM values in Marxan to conserve at least 20 % of habitat for *Alectoris chukar* and *Phasianus colchicus* in the Golestan Province. Red lines indicate boundaries of current reserves.

Fig. 3. Reservas seleccionadas utilizando distintos valores del modificador de longitud de frontera en Marxan para conservar al menos el 20 % del hábitat para Alectoris chukar *y* Phasianus colchicus *en la provincia de Golestán. Las líneas rojas indican las fronteras de las reservas actuales.*

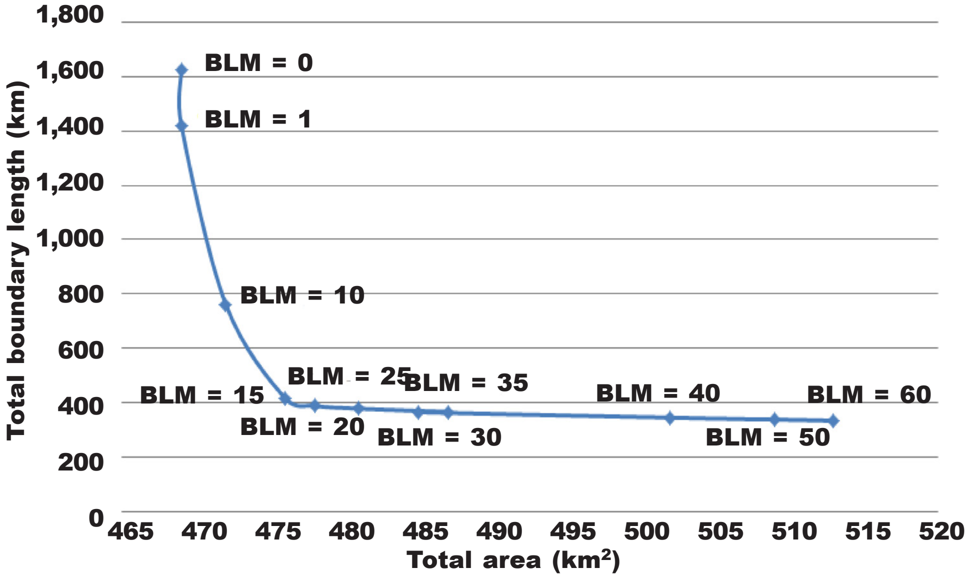

Fig. 4. Boundary/area curve used to find the optimum BLM value.

Fig. 4. Curva frontera/superficie utilizada para encontrar el valor óptimo del modificador de longitud de frontera.

In our study, the cost was considered to be equal to the total area of the selected reserves, the boundary was the total length of the boundary surrounding the selected habitats, and both species received the same SPF (species penalty factor: weighting factor for the conservation feature). The penalty term is a penalty associated with each under–represented conservation feature, and the cost threshold penalty is a penalty applied to the objective function if the target cost is exceeded.

Results

Habitat suitability

Figure 2 shows habitat suitability maps for *Alectoris chukar* and *Phasianus colchicus*. Accuracy assessment of models showed results were in the acceptable range as indicated by the calculated pAUCs, which were 0.773 and 0.719 for the chukar partridge and the common pheasant, respectively. Assessment of habitat suitability values at occurrence points showed that the selected threshold (150) was relatively close to the minimum suitability value of the occurrences (183.6 for the chukar partridge and 165 for the common pheasant). The areas of suitable habitat were mainly located in the southern parts of the province and represented 1,475 km^2 for *Alectoris chukar* and 2,150 km^2 for *Phasianus colchicus*. These areas are higher and have more vegetation cover than central and northern parts of the province.

Reserve selection

Visual inspection of the selected habitats showed that applying higher BLM values caused selection of a more compact reserve system (fig. 3). The total area of the selected reserves ranged between 513 km^2 for BLM = 60, and 469 km^2 for BLM = 0 (fig. 4).

Boundary/area comparison

To select an optimal BLM value, the total area and total boundary length of the reserve system were important factors. Stewart and Possingham (2005) suggested that boundary/area curve is a good tool to select an optimum BLM value. Figure 4 compares boundary/area in the various BLM values used in this study. According to the boundary/area ratio, when the BLM value is 15, the selected reserve system is the optimum solution.

Discussion

In recent years, Iran's Department of Environment (DOE) has endeavored to conserve biodiversity but because of the shortage of funds and experts, these efforts have not fully achieved their set goals (Makhdoum, 2008). In most cases, protected areas in Iran have been selected on an *ad hoc* basis and consequently they do not necessarily fit conservation objectives and goals as shown by Momeni et al. (2013). Hence, it is time to use and apply up–to–date methods for reserve selection and species conservation.

A comparison of the optimum reserves selected by Marxan (BLM = 15) and the current reserve system in Golestan Province showed little overlap between the optimum reserves and the available reserves (from seven newly identified patched, only two patches are located in the current reserves). The current reserve network contained only 23 % (112 km^2) of the total area of reserve selected by Marxan (476 km^2). Hence, we found it necessary to introduce new zones as protected areas to conserve 20 % of the suitable habitats of *Alectoris chukar* and *Phasianus colchicus* in the Golestan Province. The key note about the newly selected areas is that these areas are mainly near the current reserves and so it is relatively straightforward to complement current reserves through corridors. Because this study is based only on two bird species, we suggest hunting restrictions in selected areas (no–hunting area). If future studies indicate that these patches are also important habitats of other species, then promoting conservation level of the selected patches to protected areas can be considered.

It is also notable that primary polygons of suitable habitats of species and occurrence data are gathered from experienced wildlife wardens without any sampling design and hence there might be some bias in the results, which is worthy of further research.

Furthermore, the results of this study showed the possibility to approach conservation of the target species even in regions with limited data on the occurrence of the species and lack of habitat suitability maps. This lack was partially tackled using the coarse filter multi–criteria evaluation approach that refined the general and large areas of occurrences defined by field experts and wildlife wardens. In Iran, like many other developing countries, the data for some species distribution is limited and of low–quality, making conservation planning more difficult in these instances. As suggested by Store and Kangas (2001), we showed that the MCE approach coupled with the systematic reserve selection, namely Marxan, can help researchers form a good general picture of suitable habitats for a species to be conserved.

Acknowledgements

We express our gratitude to the anonymous reviewers of the earlier version of the manuscript.

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