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Integration of anthropogenic threats and biodiversity value to identify critical sites for biodiversity conservation

Azade Mehri[a], Abdolrassoul Salmanmahiny[a], Ali Reza Mikaeili Tabrizi[a], Seyed Hamed Mirkarimi[a] and Amir Sadoddin[b]

[a]Department of the Environment, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran; [b]Department of the Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

ABSTRACT

In this study, the goal was to identify critical sites for biodiversity conservation in the Gharesoo River Basin, Iran, based on integration of anthropogenic threats and biodiversity value. Firstly, the spatial patterns of threats were evaluated by combination of 13 anthropogenic threats using multi-criteria evaluation (MCE) method. Next, the spatial distribution of biodiversity value was mapped via assigning an expert-based value to each land type as habitat for mammals and bird species. Finally, the critical sites for biodiversity conservation were identified by combination of spatial threats and biodiversity value layers. We developed five threat-driven or value-driven scenarios using different weights for biodiversity threats and value. The result showed that, 7% of the river basin had very high conservation priority. We proposed 21 patches as critical sites for biodiversity conservation. Our results can be used by conservation planners to target conservation efforts towards selecting new conservation areas in Gharesoo River Basin.

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1. Introduction

Despite the suite of benefits that biodiversity provides to humanity (Cardinale et al. 2012), the rate of biodiversity loss is increasing, and many species have been threatened all around the world (Lu et al. 2014; Naoe et al. 2015). It is accepted that human influence is the ultimate driver of the biodiversity crisis (Evans et al. 2011). Dramatic changes in ecosystems due to human activities such as urban and industrial development, conversion of natural forest to farmlands, oil and gas extraction, grazing pressure and infrastructure development lead to habitat degradation, fragmentation and consequent biodiversity loss (Ramirez-Villegasa et al. 2012).

Protected areas have been accepted as the most effective conservation measure to prevent biodiversity loss (Lewis 1996). Many studies have attempted to identify new protected areas that efficiently meet conservation goals for a range of biodiversity features (Pearce et al. 2008; Jenkins et al. 2010; Momeni Dehaghi et al. 2013; Mehri et al. 2014, 2017; Asadolahi et al. 2017). In most of these studies, the emphasis has been on identifying outstanding features of biodiversity such as suitable habitats, species richness, endemism, and rarity and less attention has been given to the factors that threaten biodiversity (Rouget et al. 2003; Reyers 2004). However, in addition to inclusion of biodiversity in

CONTACT Azade Mehri Az.mehri@yahoo.com

conservation planning, investigation of the threats that impact on natural habitats and biodiversity is also needed (Ramirez-Villegasa et al. 2012). Identifying and quantifying human-induced threats to conservation targets and biodiversity enhance the long-term effectiveness of conservation planning (Mattson and Angermeier 2007; McPherson et al. 2008). Over the past several years, many studies have relied on analysis of threats to biodiversity to aid conservation prioritization and planning (Rossi et al. 2008; Fuller et al. 2010; Paukert et al. 2010; Ramirez-Villegasa et al. 2012; Reddy et al. 2014; Mirzaei et al. 2015). Various threat criteria have been used in these studies. For example, Mirzaei et al. (2015) determined the spatial pattern of biodiversity threats at landscape level in Golestan Province, Iran. They used 12 criteria in 4 main groups including structural, compositional aspects of biodiversity, non-biological threats and isolation. They assigned the highest weight to compositional aspects, including presence of species at risk. Fuller et al. (2010) created composite maps that integrated information on infrastructure, biology and physical factors related to known threats to biodiversity in Indonesia. They aggregated the 12 factors into three logical groups, including access, biological and physical groups. The results showed when physical factors were assigned more weight, the area with higher threats levels increased. Paukert et al. (2010) compared four watershed-scale ecological threat indices for the Lower Colorado River Basin using landscape-level threats of land use, waterway development and diversions, and human development. Each threat was measured for severity and frequency throughout each watershed. The result showed threat indices were highly correlated and were highest for watersheds close to urban centres. Road crossings and density were the most influential threats.

Evaluation of impacts of multiple anthropogenic threats on biodiversity and natural ecosystems guide the formulation of strategies for biodiversity conservation (Reddy et al. 2014). Anthropogenic threats reflect real conflicts between biodiversity conservation and human activities, and affects viability of conservation targets (Mattson and Angermeier 2007; Pressey and Bottrill 2008).

Threats are a key factor in scheduling conservation action after the design of a regional conservation plan (Pressey and Bottrill 2008). Threats assessment and prioritization of areas that face increasing threats can help in taking targeted conservation efforts (Reddy et al. 2014). Conservation areas should be able to mitigate the threats to biodiversity (Wilson et al. 2005).

In the present study, the anthropogenic threats and biodiversity value were integrated to assess conservation priorities in the Gharesoo River Basin, Golestan Province, Iran. The Gharesoo River Basin is an area of exceptionally high biodiversity and conservation priority. However, it has been subject to multiple anthropogenic threats such as clear-cutting of forest for agriculture, transportation, mining and rapid urban and industrial development. These threats have led to habitat and biodiversity loss in the region. So, identifying priority areas for conservation activities is a necessity to deal with these problems.

Advances in GIS technology and remote sensing have facilitated the spatial investigation of threats and environmental change in large spatial scales (Reddy et al. 2014). The distribution of anthropogenic threats can be spatially modelled using multi-criteria decision analysis. In this analysis, several criteria are evaluated and combined to meet a particular purpose (Nackoney and Williams 2012). We used a GIS-based multi-criteria evaluation (MCE) to identify spatial patterns of threats to biodiversity. MCE was developed as a spatial decision support tool for land use planning which facilitated the integration of social, political, environmental and economic requirements with suitability analysis. This ability has been enhanced with integration of MCE and GIS and perhaps it could be described as the most fundamental of decision support operations in GIS. MCE is noted for its capacity to assign varying importance to different criteria according to stakeholder preferences, simplicity, capacity to handle many different types of criteria and ability to facilitate decision-making under varying level of uncertainty. Using fuzzy set theory allows more flexible MCE operations which takes into account the continuity and uncertainty in the relation between the criteria and the decision set (Wood and Dragicevic 2007). Using GIS-MCE technique in the present study enables the spatial distribution of different threats to be evaluated and compared. So, several criteria can be combined into a single composite index of threats and applied across the whole of the study area (Fuller et al. 2010).

Also, we used habitat suitability of mammals and birds to model spatial distribution of biodiversity value in the river basin. Habitat models indirectly serve as surrogates of biodiversity variables (Marcot 2006). Investigation of habitat status is a key issue for prioritizing sites in conservation planning (Reddy et al. 2014). The loss of critical habitats may result in the extinction of many species and identifying and protecting them has become one of the main uses of habitat suitability models for conservation purpose (Lauria et al. 2015).

The goal of the present study was to identify critical sites for biodiversity conservation in the Gharesoo River Basin. The specific objectives were to (1) model spatial patterns of anthropogenic threats to biodiversity, (2) evaluate spatial distribution of biodiversity value, (3) identify conservation priorities by combination of spatial threats and biodiversity value layers. Figure 1 illustrates a research flowchart of the study.

2. Materials and methods

2.1. Study area

The Study was conducted in Gharesoo River Basin in Golestan Province, northern Iran (Figure 2). The region covers approximately 161528 hectares, located in northern slopes of the Alborz Mountains and is close to the south-eastern coast of the Caspian Sea. Dense and semi-dense forest areas and rangelands cover approximately 39 and 5% of the region in the south, respectively. In the northern part, agricultural lands dominate the landscape and cover 48% of the river basin. The altitude varies from −99 m in the north to about 3213 m in the south-east. The climate is humid, with average annual rainfall of 552 mm and mean annual temperature of 15° C. The Gharesoo River Basin is an area of exceptionally high biodiversity and conservation priority. The natural forest vegetation is a temperate deciduous broad-leaved forest and is part of Caspian Hyrcanian mixed forests. This forest includes valuable species such as *Quercus castaneifolia, Fagus orientalis, Alnus subcordata, Acer velutinum, Sorbus torminalis, Ulmus glabra, Tilia begonifolia, Acer cappadocicum, Fraxinus excelsior, Juglans regia*, etc. The forest cover has unique biodiversity and provides habitat for a wide range of plant and animal species. This region is an important resting area for birds migrating between Russia and Africa and is thus a key habitat for many bird species. Jahan-Nama is the only protected area in Gharesoo River Basin, located in the south-west of the river basin (Figure 2). The Gharesoo River Basin has been subject to multiple anthropogenic threats such as clear-cutting of forest for agriculture, transportation, mining and rapid urban and industrial development. These problems have led to habitat fragmentation and a decline in biodiversity of the region (GUASNR 2013; Mehri 2018).

2.2. Spatial assessment of threats to biodiversity

A review of studies on evaluation and modelling biodiversity threats, illustrated the diversity of criteria used (Fuller et al. 2010; Jarvis et al. 2010; Ramirez-Villegasa et al. 2012; GUASNR 2013; Reddy et al. 2014; Mirzaei et al. 2015; Mehri 2018). Based on these studies, data availability, and consulting with local experts, 13 anthropogenic threats which had the most negative impacts on habitats and biodiversity in the river basin, were selected (Table 1). The primary data were collected from the Golestan Province land use planning report (GUASNR 2013). Distance criteria layers were calculated as distance value of each pixel to the nearest target pixels. Deforestation likelihood layer was prepared using Logistic regression method. Seven variables including distance to roads, slope, elevation, distance to rivers, distance to residential area, vegetation density and distance to forest edge were used in the modelling process. The result was a deforestation prediction layer with values in the range of 0 to 1, with higher values indicating relatively higher propensity for deforestation. Relative operating characteristic (ROC) value was 0.9535, showing the success of the modelling.

We employed a GIS-based, multi-criteria evaluation (MCE) to identify spatial patterns of threats to biodiversity. Over the past several years, spatial MCE approach has been used in a wide range of

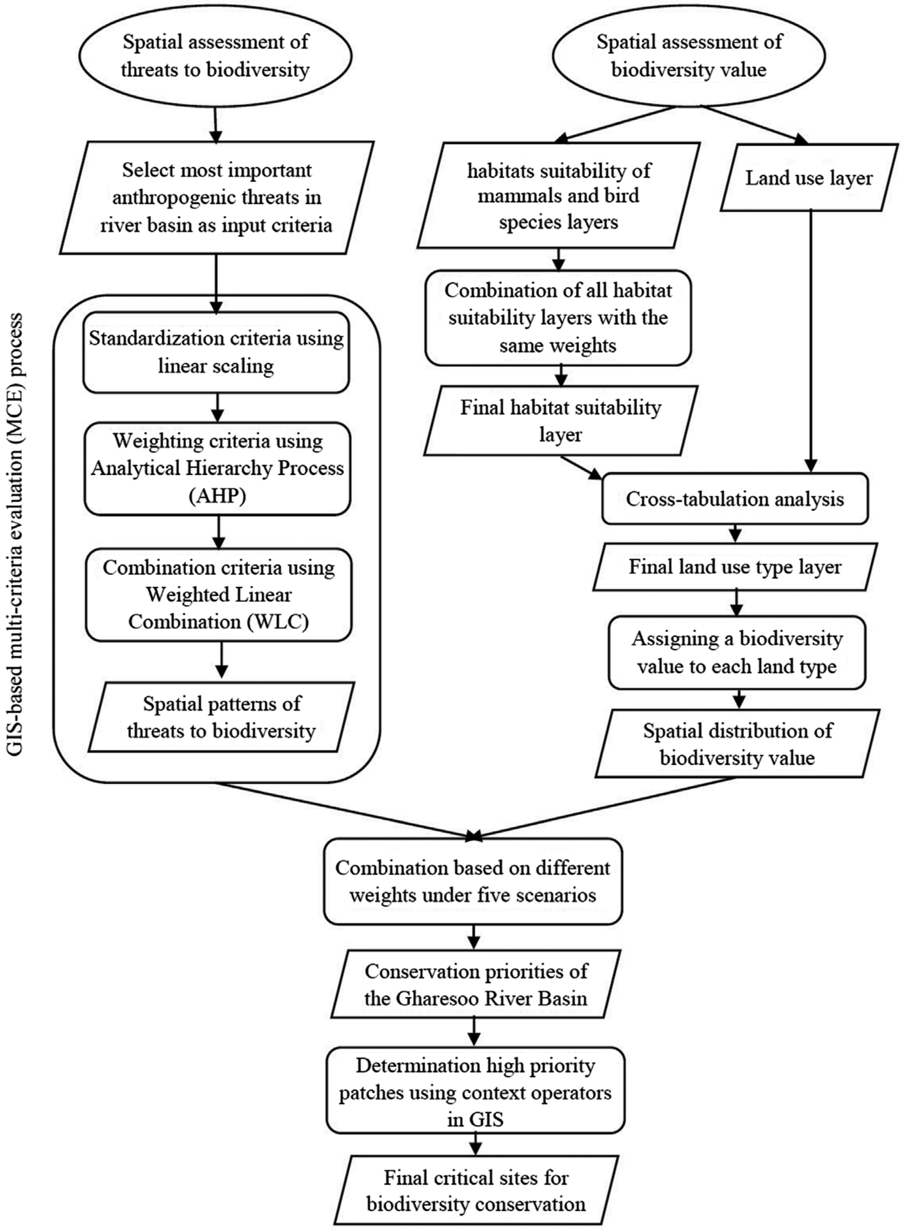

Figure 1. Research flowchart of the study.

studies in the world to identify conservation priorities and threats (Boteva et al. 2004; Wood and Dragicevic 2007; Fuller et al. 2010; Panitsa et al. 2011).

The first issue in MCE is how to combine the data from different criteria to form a single index of evaluation (Eastman 2012). We used the Weighted Linear Combination (WLC) method, that is most commonly used technique for combination of continuous criteria (Voogd 1982). Firstly, each criterion was multiplied by a weight, then all weighted criteria were summed to yield a spatial threats layer (Equation (1)) (Eastman 2012).

$$S = \sum w_i x_i \tag{1}$$

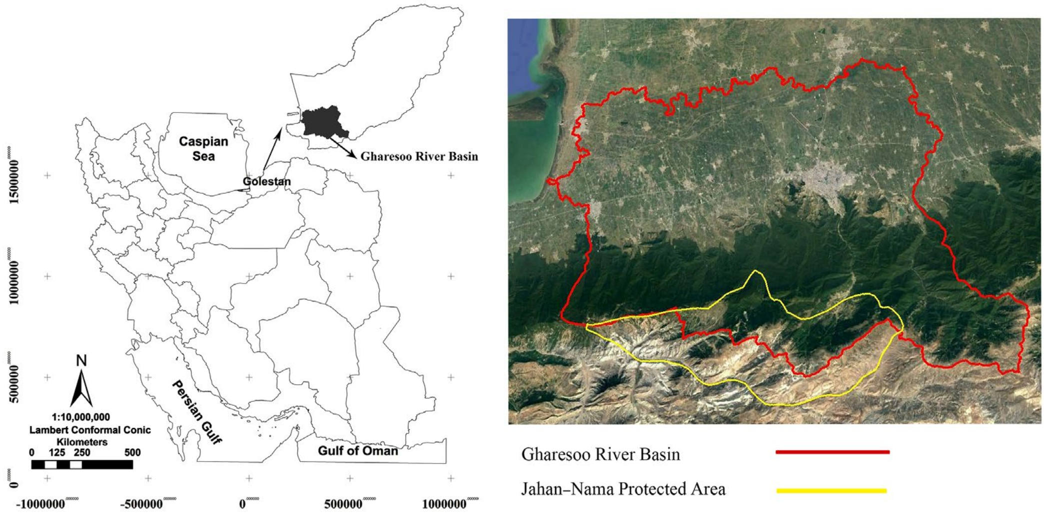

Figure 2. Location of the Gharesoo River Basin in Golestan Province of Iran.

Table 1. The standardization methods and weights of threats criteria.

Threats (units of measure)	Standardization methods	Break points	Weights
Distance to residential areas (m)	Linear ↓	500, 10,000	0.117
Distance to industrial areas (m)	Linear ↓	500, 10,000	0.036
Distance to main roads (m)	Linear ↓	500, 5000	0.139
Distance to secondary roads (m)	Linear ↓	500, 5000	0.147
Distance to railroads (m)	Linear ↓	500, 5000	0.111
Distance to mines (m)	Linear ↓	1000, 5000	0.036
Distance to airport (m)	Linear ↓	2000, 10,000	0.014
Distance to dams (m)	Linear ↓	1000, 10,000	0.021
Distance to oil pipelines (m)	Linear ↓	1000, 10,000	0.007
Distance to gas pipelines (m)	Linear ↓	1000, 10,000	0.007
Distance to power lines (m)	Linear ↓	1000, 5000	0.015
Distance to agriculture (m)	Linear ↓	500, 10,000	0.147
Deforestation Likelihood	Linear ↑	0, 1	0.203

Notes: ↑ = Monotonically increasing, ↓ = Monotonically decreasing.

where S is spatial threats layer, W_i is weight of factor i and X_i is criterion score of factor i. Because criteria are measured in different scales, they should be standardized before combination. There are several methods for standardization (Voogd 1982). The simplest methods that we have also used in this study are linear scaling (Equation (2)). This method has been used in different studies and the map generated in this way compared well with the expert opinions (Fuller et al. 2010; GUASNR 2013; Mirzaei et al. 2015).

$$X_i = (R_i - R_{\min})/(R_{\max} - R_{\min}) \times \text{standard range} \tag{2}$$

where R_i is raw score of factor i, $R_{\min}$ is minimum raw score of factor i, $R_{\max}$ is maximum raw score of factor i and standard range here is 0–255. The higher values of standardized scale (here 255) indicate relatively high threat levels. A wide range of techniques exist for development of factor weights. Here, we used Analytical Hierarchy Process (AHP), that is a pairwise comparison developed by Saaty (1977). In the MCE methods using WLC, the sum of weights should equal to one (Eastman 2012).

The standardization methods and weights of criteria are presented in Table 1. The decision about the criteria and their standardization and weights was made based on data availability, review of the relevant literature, and consultation with local experts and policy-makers.

Table 2. The biodiversity value of each land type.

ID	Land use	Value	Standardized value
1	Residential areas	0	0
2	Forest with low habitat suitability	0.8	204
3	Forest with moderate habitat suitability	0.9	229
4	Forest with high habitat suitability	1	255
5	Rangelands with low habitat suitability	0.6	153
6	Rangelands with moderate habitat suitability	0.7	178
7	Rangelands with high habitat suitability	0.8	204
8	Agriculture with low habitat suitability	0.4	102
9	Agriculture with moderate habitat suitability	0.5	128
10	Agriculture with high habitat suitability	0.6	153
11	Water resources	0.6	153
12	Rivers	0.5	128
13	Main roads	0	0
14	Secondary roads	0	0
15	Railroads	0	0
16	Industrial areas	0	0
17	Mines	0	0
18	Airport	0	0

2.3. Spatial assessment of biodiversity value

The spatial distribution of biodiversity value was based on a combination of habitats suitability of wildlife and land use classes. The land use layer was obtained from the Golestan Province land use planning report (GUASNR 2013). In this report, land use layer was derived from Landsat images using a hybrid classification method with a total accuracy of 95% and spatial resolution of 30 m. Also, visual interpretation and digitizing land features in Google Earth was used to correct land use layer (GUASNR 2013). Land use layer included 12 major classes, namely residential areas (3%), forest (39%), agriculture (48%), rangelands (5%), main roads (1%), secondary roads (1.5%), railroads (0.2%), industrial areas (0.6%), mines (0.3%), airport (0.1%) water resources (0.3%) and rivers (1%).

The final habitat suitability layer was produced through combining habitat suitability layers of 8 mammal species and 67 bird species. The habitat suitability layers were obtained from the Golestan Province land use planning report. In this report, multi-criteria evaluation (MCE) and maximum entropy (MaxEnt) methods were used to produce habitat suitability maps of mammal and bird species, respectively (GUASNR 2013). MaxEnt modelling relies only on presence data, and has proven to be very effective at determining habitat use and species distributions for a variety of species and localities (Baldwin 2009). The bird and mammal species that were considered for habitat modelling are presented in Appendices 1 and 2 (GUASNR 2013). The habitat suitability layers for all mammals and bird species were combined with the same weights, to produce a final habitats suitability layer. This final layer was divided into three suitability classes using natural breaks, including low (1–50), average (50–117) and high (117–255) habitat suitability. Then, a cross-tabulation analysis between final suitability and land use layers was performed. The cross-tabulation analysis compares images containing categorical variables of two types and indicates the spatial overlap between the classes in the input layers. Accordingly, the forest, rangeland and agriculture classes in the land use layer were divided into three suitability classes, including low, average and high habitat suitability. The new land use layer included 18 land types. Spatial data on the biodiversity value were prepared via assigning an expert-based value to each land type. We asked our experts to assign a value of 0–1 for each land type based on their importance for biodiversity conservation in the region. The biodiversity values of land types are presented in Table 2.

2.4. Critical sites for biodiversity conservation

Critical sites for biodiversity conservation were identified through combination of spatial threats and biodiversity value layers. We considered that areas under high anthropogenic threats with high

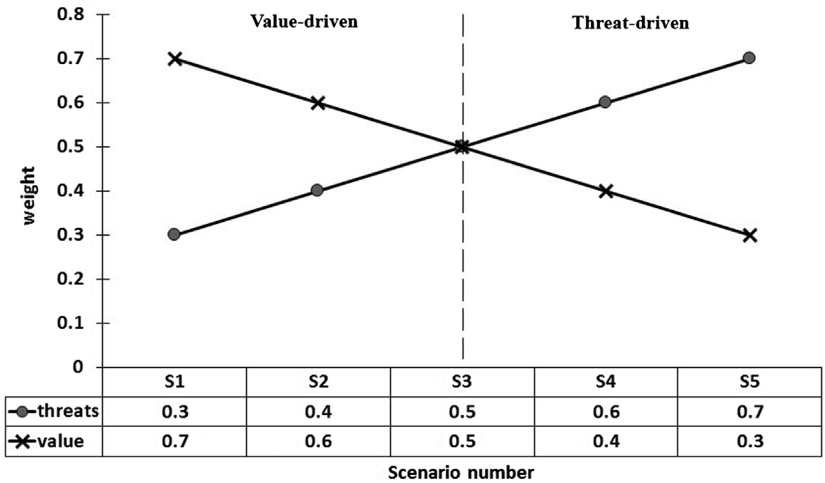

Figure 3. Weights of spatial threats and biodiversity value layers in different scenarios.

biodiversity values would have a higher priority for conservation. At first, the biodiversity value layer was transformed to the same scale of spatial threats layer (0 to 255) using linear scaling. Next, each threats and biodiversity value layers were multiplied by a weight, then weighted layers were summed to yield a spatial conservation priority layer (Equation (3)).

$$C = \left(w_{\mathrm{at}}x_{\mathrm{at}}\right) + \left(w_{\mathrm{bv}}x_{\mathrm{bv}}\right) \tag{3}$$

where C is spatial conservation priority layer, W_{at} and W_{bv} are weights of threats and biodiversity value layers, respectively, and X_{at} and X_{bv} are threats and biodiversity value layers, respectively.

We developed five scenarios using different weights (Figure 3). Conservation status of the region was evaluated based on two approaches, threat-driven and value-driven. In the threat-driven approach higher weight were assigned to threat layers, while in the value-driven approach the biodiversity value layer received higher weight.

3. Results

Figure 4 illustrates the standardized anthropogenic threats layers used to assess threats to biodiversity. Spatial patterns of threats to biodiversity (Figure 5) were assessed using MCE method based on layers presented in Figure 4. The most threatened areas were located in the middle parts of the river basin, where the forest areas are found in the vicinity of agricultural land and developed areas with consequent deforestation in the landscape. The southern and south-eastern parts of the basin were the least-threatened areas which are covered with forest and rangelands but high elevation and steep slopes make them less accessible for exploitation.

Figures 6 and 7 illustrate the final habitat suitability and land use type layers. The spatial distribution of biodiversity value (Figure 8) was assessed based on layers presented in Figures 6 and 7. This layer was derived from assigning an expert-based value to each land type. The areas with higher values have higher importance to wildlife as habitats and should be considered as priorities for implementation of conservation measures.

The layers of threats and biodiversity value were combined to identify critical sites for biodiversity conservation. Figure 9 shows the results of combination for five different scenarios. The results were divided into five conservation priority classes from ‘very low’ to ‘very high’, based on equal intervals to facilitate comparison among the outputs.

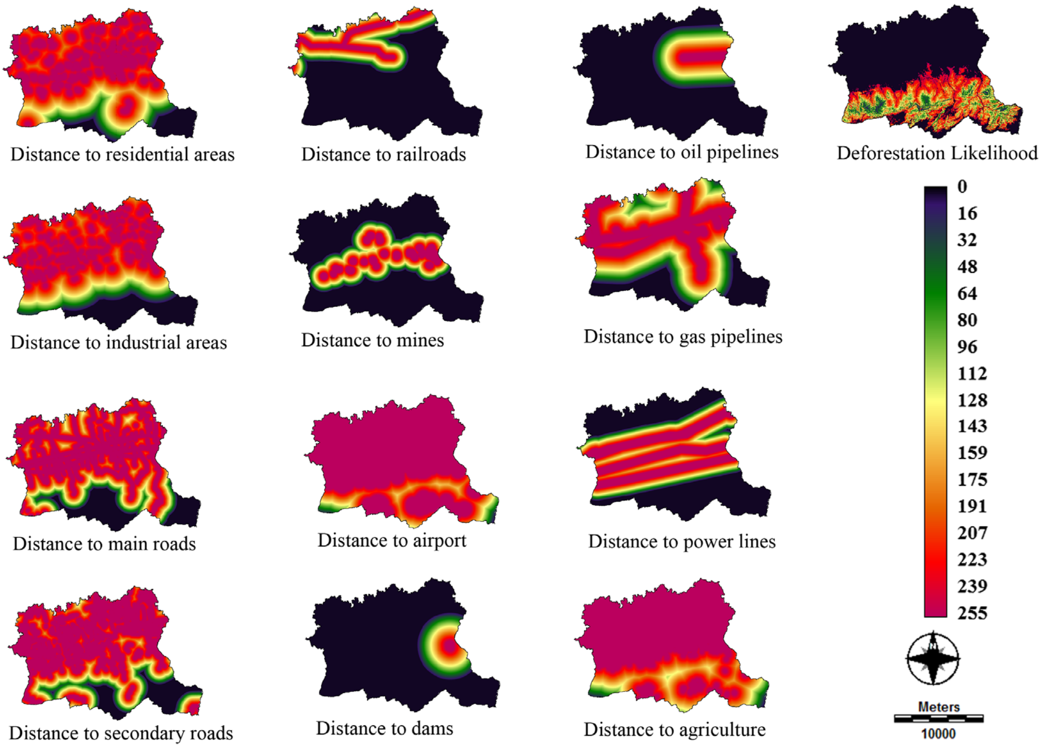

Figure 4. Standardize anthropogenic threats layers. The level of threats increases as the value rises.

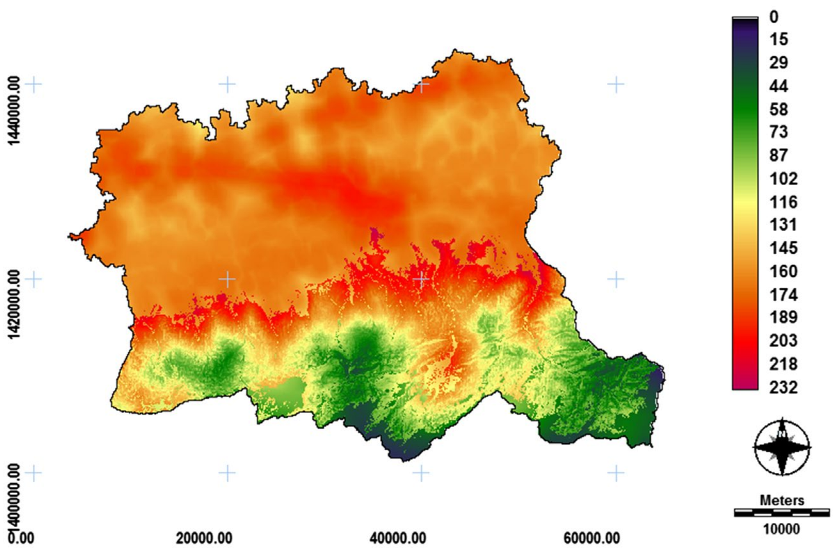

Figure 5. Spatial patterns of threats to biodiversity. The level of threats increases as the value rises.

In scenarios 1 and 2, biodiversity received higher weighs for conservation. In scenarios 4 and 5, threats layer had higher weight. In scenario 3, both layers were weighed equally. Table 3 represents the area of each conservation priority class for all scenarios. The high and very high priority classes

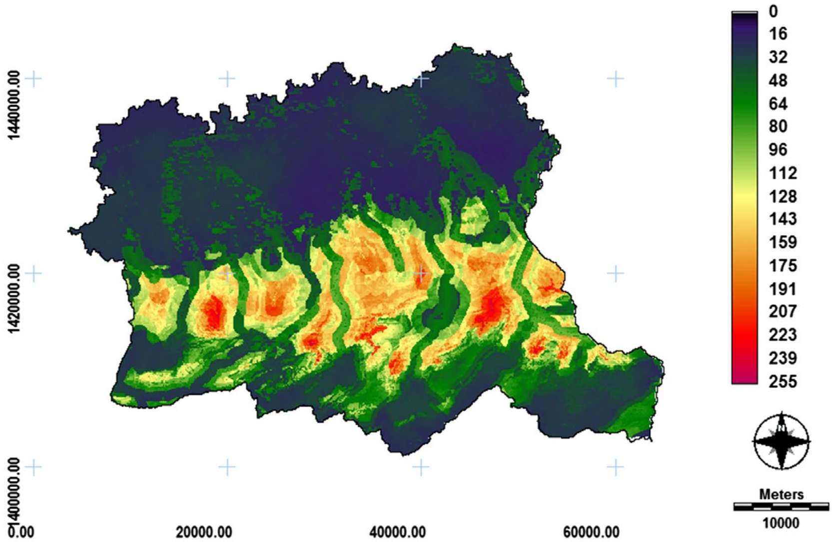

Figure 6. Final habitat suitability layer. The level of suitability increases as the value rises.

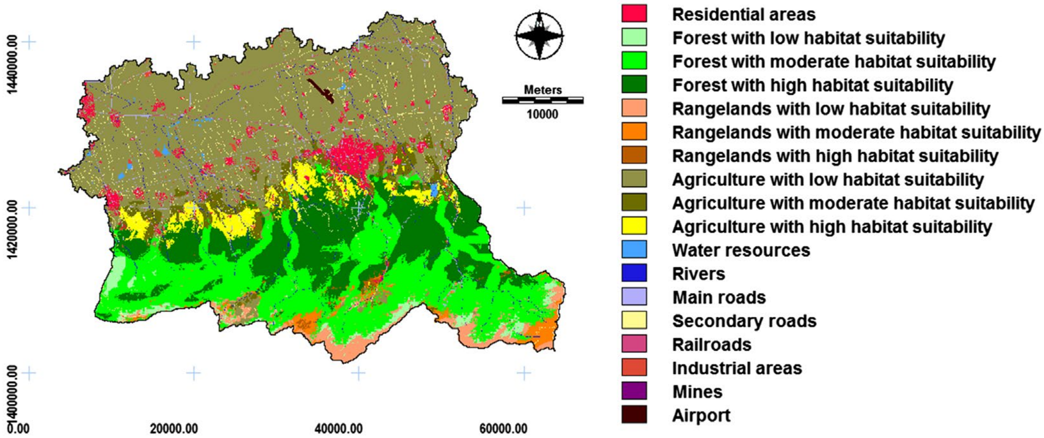

Figure 7. Final land use type layer.

showed the most variability in area, as a result of changing weights of layers. With increasing weight for threats layer and decreasing weight for biodiversity layer, the area of very high priority areas decreased from 34 to 11% of the river basin.

We considered the very high priority class as critical sites for conservation and compared them between different scenarios. We found that with increasing weights of biodiversity value from scenario 5 to 1, areas from other priority classes entered to very high priority class, while the areas of very high priority class showed no change. In other words, the areas with very high priority in scenario 5, had very high priority in all scenarios; the areas with very high priority in scenario 4, had very high priority in scenarios 1–3; the areas with very high priority in scenario 3, had very high priority in scenarios 1 and 2; and finally, the areas with very high priority in scenario 2, had very high priority in scenario 1.

Based on these findings, the very high priority areas in scenario 5 were the overlapping areas among all scenarios and could be considered as final critical sites for biodiversity conservation. These areas had an area of 17463 hectares and contained 11% of the Gharesoo River Basin. Using context

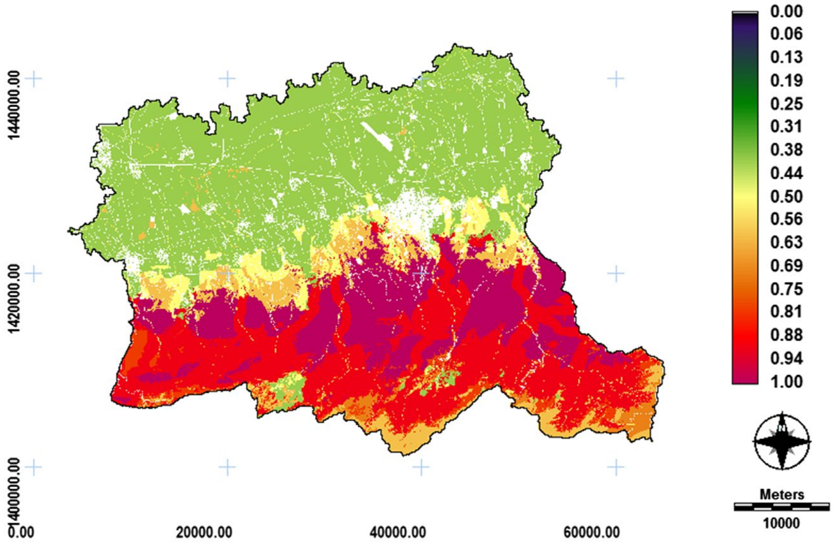

Figure 8. Spatial distribution of biodiversity value. The biodiversity increases as the value rise.

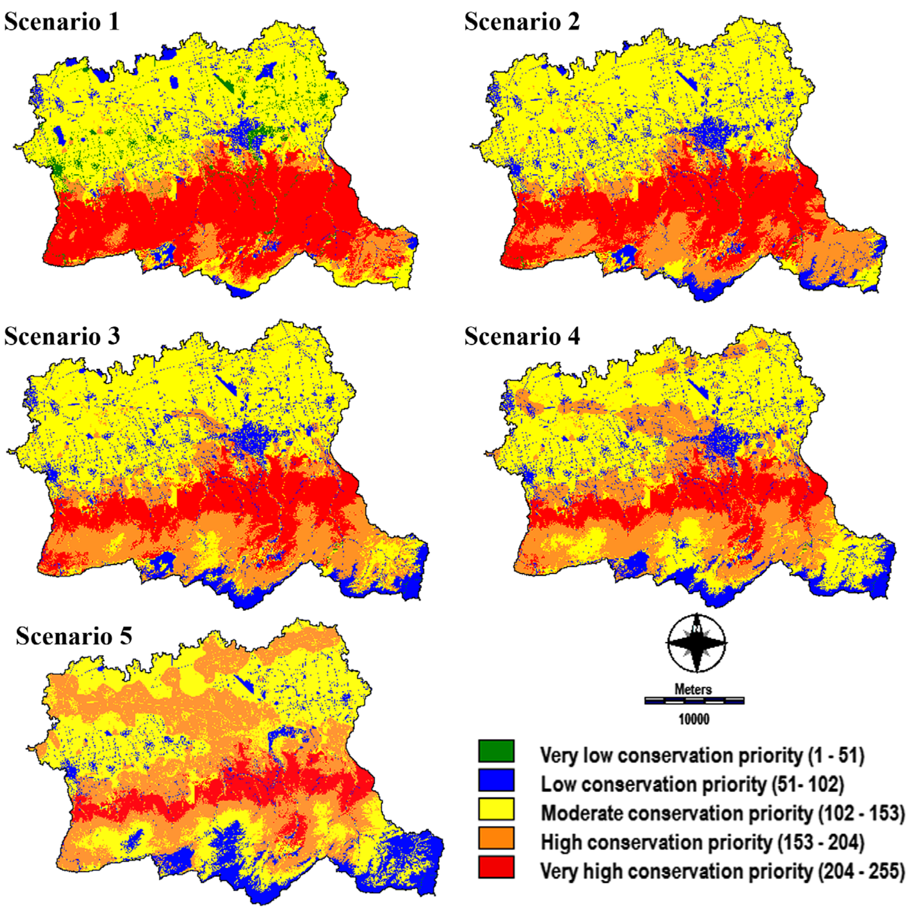

Figure 9. Conservation priorities of the Gharesoo River Basin based on combination of anthropogenic threats (AT) and biodiversity value (BV). The weights of the two layers in different scenarios (S) were (AT, BV): S1(0.3, 0.7); S2 (0.4, 0.6); S3 (0.5, 0.5); S4 (0.6, 0.4); and S5 (0.7, 0.3).

operators in GIS, the most compact patches with minimum area of 100 hectares were extracted and prioritized based on their average conservation value. Final critical sites for conservation are showed in Figure 10. Table 4 represents descriptive statistics of critical sites.

4. Discussion

The severity of threats to biodiversity and ecosystems affects viability of conservation targets (Mattson and Angermeier 2007). Information on threatening factors and distribution of threatened areas is crucial for effective conservation planning (Wilson et al. 2005). Hence, in addition to consideration of biodiversity value, understanding of the threats affecting biodiversity is a necessity for conservation planning (Jarvis et al. 2010). To meet this goal, the present study attempted a prioritization of critical sites for biodiversity conservation in the Gharesoo River Basin. We considered that the areas under high anthropogenic threats and high biodiversity values would have a higher priority for conservation.

The distribution of anthropogenic threats can be spatially modelled using multi-criteria decision analysis (Nackoney and Williams 2012). In our study, the spatial patterns of threats to biodiversity were evaluated by combination of 13 anthropogenic threats using MCE method. This layer provided information for the ecosystem management and helped identify areas that are more exposed to biodiversity loss.

Table 3. The area of each conservation priority class in different scenarios.

Scenario	Threats weight	Biodiversity value weight	Area of conservation priority classes in hectare (% of the river basin)				
			Very low	Low	Moderate	High	Very high
1	0.3	0.7	5093.78 (3%)	10,236.61 (6%)	76,104.47 (47%)	15,389.80 (10%)	54,703.05 (34%)
2	0.4	0.6	232.63 (0.14%)	15,984.51 (10%)	75,604.28 (47%)	28,544.88 (18%)	41,161.40 (25%)
3	0.5	0.5	97.89 (0.06%)	18,350.60 (11%)	75,393.44 (47%)	38,192.25 (24%)	29,493.53 (18%)
4	0.6	0.4	66.22 (0.04%)	19,618.81 (12%)	73,456.14 (45%)	46,241.46 (29%)	22,145.07 (14%)
5	0.7	0.3	19.58 (0.01%)	19,878.70 (12%)	65,479.67 (41%)	58,687.16 (36%)	17,462.61 (11%)

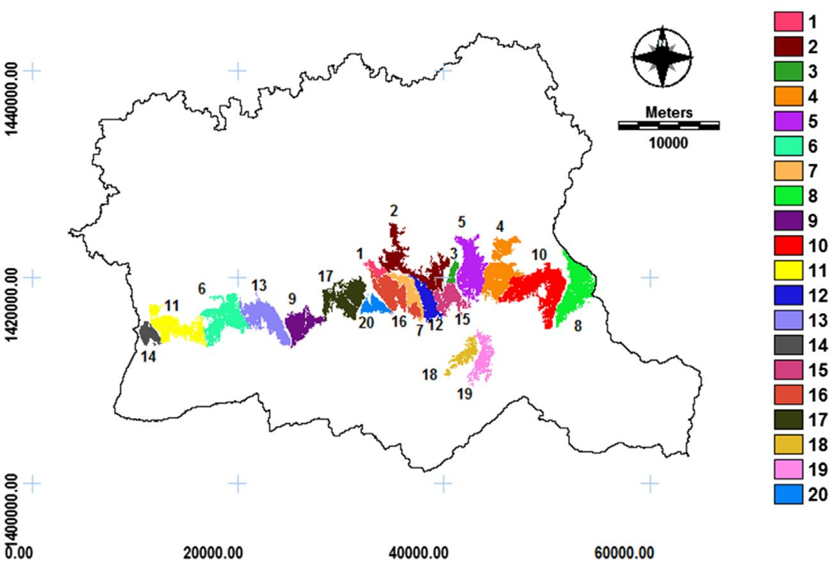

Figure 10. Prioritization of critical sites for biodiversity conservation in Gharesoo River Basin. The priority of sites increases as the value rises.

Table 4. The average of spatial threats and biodiversity value layers in each critical site for biodiversity conservation.

Critical sites id	Average threats	Average biodiversity value	Average conservation value
1	204.39	255.00	219.56
2	203.38	251.99	217.96
3	201.30	254.71	217.31
4	193.11	248.62	209.77
5	194.47	242.79	208.96
6	186.25	254.53	206.74
7	184.52	254.96	205.64
8	184.81	251.79	204.91
9	183.50	249.72	203.38
10	182.84	249.14	202.73
11	182.82	248.70	202.60
12	180.65	253.79	202.60
13	181.55	248.54	201.64
14	185.89	237.72	201.43
15	179.89	244.66	199.35
16	175.48	255.00	199.33
17	175.77	242.01	195.65
18	168.79	252.08	193.78
19	175.20	236.49	193.60
20	168.02	252.75	193.45

The spatial distribution of biodiversity value was shown via assigning an expert-based value to each land type based on habitat suitability of mammals and bird species. Investigation of habitat status has become key issue for prioritizing sites in conservation planning. Habitat suitability models have the potential to become an essential tool to support management decisions and conservation measures (Lauria et al. 2015). Habitat loss is one of the important detrimental impacts to biodiversity which results in loss of biodiversity, population connectedness and gene flow (Niemandt and Greve 2016). Hence, the high-suitability habitats should be considered as priority for implementation of conservation measures.

Because financial resources for conservation are scarce, there is a need for identifying priorities for conservation actions. Ideally habitats that have already been modified should receive more attention than those relatively free of human activities (Rouget et al. 2003). In order to identify conservation priorities in the Gharesoo River Basin, we combined two layers of anthropogenic threats and biodiversity value. Our results showed that high and very high conservation priority areas covered 42–47% of the river basin depending on different scenarios. We proposed 20 patches as critical sites for biodiversity conservation. All of these areas were located in the middle parts of the river basin, where the forest areas are found in the vicinity of agricultural land and developed areas. Like our results, Mirzaei et al. (2015) illustrated central parts of the Golestan province were more exposed to biodiversity threats. Although they did not use the same criteria as ours, but they final threat map showed a similar distribution pattern with our biodiversity threats layer. Also, Paukert et al. in Lower Colorado River Basin found that threat indices were highest for watersheds close to developed areas such as urban centres.

Despite the importance of these sites as the most suitable habitats for mammals and bird species in the region, they are subject to multiple anthropogenic threats such as clear-cutting of forest for agriculture, transportation, mining and rapid urban and industrial development. Hence, there is an urgent need for conservation practices to manage biodiversity and reduce threats in these areas. In future studies, the impact of conservation practices, such as reforestation on the level of threats can be explored. This allows planners to anticipate both the positive and negative consequences of each practice and make conservation planning more effective (Wilson et al. 2005).

The prioritize areas for biodiversity conservation in the present study can be used by conservation planners to target conservation efforts and as a basis for selecting new conservation areas in the

Gharesoo River Basin. The areas with very high conservation priority should be given special attention for mitigation measures and prevention biodiversity loss.

Our definition of critical sites for conservation considered two important aspects of conservation measures, including biodiversity value and threats, which make the approach worthier of attention. These sites covered 9% of the river basin and about 1% of critical sites were within the existing protected areas. Jahan-Nama is the only protected area in the river basin that covers approximately 9% of the region in southern part. This area had high biodiversity value (average value of 0.8, considering our biodiversity value output in the range 0–1), and was subject to moderate threats level (average value of 84, considering our spatial threats output in the range 0–255). It seems that this protected area has a positive effect on reducing the risk of biodiversity loss and human activities. This emphasizes the necessity to protect our proposed critical sites and connects them to national conservation network. However, unlike our result, Fuller et al. (2010) rejected the hypothesis that established protected areas in Indonesia were generally less threatened than areas that do not benefit from formal protection.

Our approach provided a practical framework to develop a spatial database on biodiversity threats. The decision-makers and conservation planners can apply different threat-driven or value-driven scenarios with preferred weight for biodiversity value and threats and investigate their impacts on area and spatial arrangement of critical sites. The proposed approach has the potential to use in other river basins in Golestan and other provinces in Iran for the comparison of the conservation significance between the different river basins and investigation of overlap between biodiversity hotspots and current protected areas.

5. Conclusion

Identifying priority areas for conservation activities is necessary to deal with human pressures and habitat loss in the Gharesoo River Basin. Investigation of threats is widely considered as a critical component of effective conservation planning. In the present study, the goal was to identify critical sites for biodiversity conservation in the Gharesoo River Basin, based on integration of anthropogenic threats and biodiversity value. The habitat suitability of mammal and bird species was used as surrogates for biodiversity value. Considering the limited financial resources for nature conservation, decision-makers should direct their attention to those areas with more priority and those requiring mitigation for biodiversity and threats. In this regard, the present study prioritized several patches as critical sites for biodiversity conservation. Comparison of our spatial threats output with the current conservation areas in river basin illustrated that these areas are less threatened than areas that do not benefit from formal protection. Only about 1% of critical sites for conservation were within the existing protected areas. This emphasizes that to conserve biodiversity, introducing new protected areas is essential in Gharesoo River Basin. Conservation areas have an important role to preserve habitats, provide adequate opportunities for species to adapt or relocate, maintain or increase native vegetation cover, protect threatened and endangered species from hunting. Relative to other conservation studies in the region that only address biodiversity values, our approach integrates both biodiversity values and threats to identify areas with high conservation priority. Our results provide conservation planners with new spatial information on biodiversity values and threats that can guide future selection of areas for biodiversity conservation.

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Disclosure statement

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Appendix 1. The main bird species in the Gharesoo River Basin that was considered for habitat modelling

Id	Scientific name	Order	Family
1	*Glareola pratincola*	Charadriiformes	Glareolidae
2	*Charadrius dubius*		Charadriidae
3	*Charadrius alexandrinus*		
4	*Vanellus leucurus*		
5	*Himantopus himantopus*		Recurvirostridae
6	*Chlidonias leucopterus*		Laridae
7	*Sterna albifrons*		
8	*Philomachus pugnax*		Scolopacidae
9	*Actitis hypoleucos*		
10	*Phalaropus lobatus*		
11	*Numenius arquata*		
12	*Tringa ochropus*		
13	*Tringa glareola*		
14	*Tringa erythropus*		
15	*Ardea purpurea*	Ciconiiformes	Ardeidae
16	*Ardea cinerea*		
17	*Ceryle rudis*	Coraciiformes	Alcedinidae
18	*Coracias garrulus*		Coraciidae
19	*Merops persicus*		Meropidae
20	*Merops apiaster*		
21	*Accipiter nisus*	Falconiformes	Accipitridae
22	*Accipiter badius*		
23	*Pernis apivorus*		
24	*Buteo buteo*		
25	*Buteo rufinus*		
26	*Circus aeruginosus*		
27	*Falco naumanni*		Falconidae
28	*Falco tinnunculus*		
29	*Coturnix cotrunix*	Galliformes	Phasianidae
30	*Phasianus colchicus*		
31	*Alectoris chukar*		
32	*Certhia familiaris*	Passeriformes	Certhiidae
33	*Emberiza bruniceps*		Emberizidae
34	*Emberiza cia*		
35	*Garrulus glandarius*		Corvidae
36	*Riparia riparia*		Hirundinidae
37	*Parus lugubris*		Paridae
38	*Parus major*		
39	*Parus ater*		
40	*Aegithalos caudatus*		
41	*Parus caeruleus*		
42	*Ficedula parva*		Muscicapidae
43	*Muscicapa striata*		

(*Continued*)

Appendix 1. (*Continued*)

Id	Scientific name	Order	Family
44	*Acrocephalus stentoreus*		Sylviidae
45	*Sitta tephronota*		Sittidae
46	*Sitta europaea*		
47	*Troglodytes troglodytes*		Troglodytidae
48	*Fringilla coelebs*		Fringillidae
49	*Lanius collurio*		Laniidae
50	*Lanius minor*		
51	*Lanius isabellinus*		
52	*Galerida cristata*		Alaudidae
53	*Luscinia megarhynchos*		Turdidae
54	*Cercotrichas galactotes*		
55	*Phoenicurus ochruros*		
56	*Oenanthe finschii*		
57	*Oenanthe isabellina*		
58	*Oenanthe oenanthe*		
59	*Erithacus rubecula*		
60	*Turdus merula*		
61	*Monticola saxatilis*		
62	*Picoides major*	Piciformes	Picidae
63	*Dendrocopos minor*		
64	*Picus viridis*		
65	*Podiceps cristatus*	Podicipediformes	Podicipedidae
66	*Strix aluco*	Strigiformes	Strigidae
67	*Athene noctua*		

Appendix 2. The main mammal species in the Gharesoo River Basin that was considered for habitat modelling

Id	Scientific name	Order	Family
1	*Lynx lynx*	Carnivora	Felidae
2	*Panthera pardus*		
3	*Lutra lutra*		Mustelidae
4	*Ursus arctos*		Ursidae
5	*Cervus elaphus*	Artiodactyla	Cervidae
6	*Capreolus capreolus*		
7	*Capra aegagrus*		Bovidae
8	*Ovis orientalis*		