

1 **Spatial assessment of biodiversity and conservation priorities in Hamedan Province, Iran, using a**
2 **landscape ecology approach**

3
4 **Abstract**

5
6 Systematic conservation planning is a framework that has been developed over the past decade to prioritize the
7 management of key habitats and conserve biodiversity values. Artificial intelligence has been proposed to operate
8 within this framework by using computer algorithms based on an objective function to identify and prioritize protected
9 area networks. In this context, our objective was to determine the optimal conservation network for biodiversity in the
10 Hamedan Province of Iran. Using a Tabu search algorithm, we determined which area would accommodate the
11 greatest number of biodiversity targets within the smallest area possible. The selected conservation patches were
12 investigated for their connectivity and compactness using landscape composition and configuration metrics. In
13 addition, we applied Redundancy Analysis (RDA) to determine the relationship between conservation targets and
14 landscape parameters such as land use/ cover types, and species richness. The results indicated that the existing
15 protected area network is insufficient to attain conservation goals in Hamedan Province, Iran. The landscape metrics
16 analysis revealed that patches with more contiguity, compaction, and fractal dimension hold a higher conservation
17 value and RDA showed a clear relation between landscape metrics and conservation targets. We thus suggest that our
18 results be used by land managers and land use planners to better align conservation and management strategies in an
19 effort to maximize biodiversity conservation.

20
21 **Keywords:** Conservation Priority, ConsNet, Landscape Criteria, Tabu Search Algorithm, Iran
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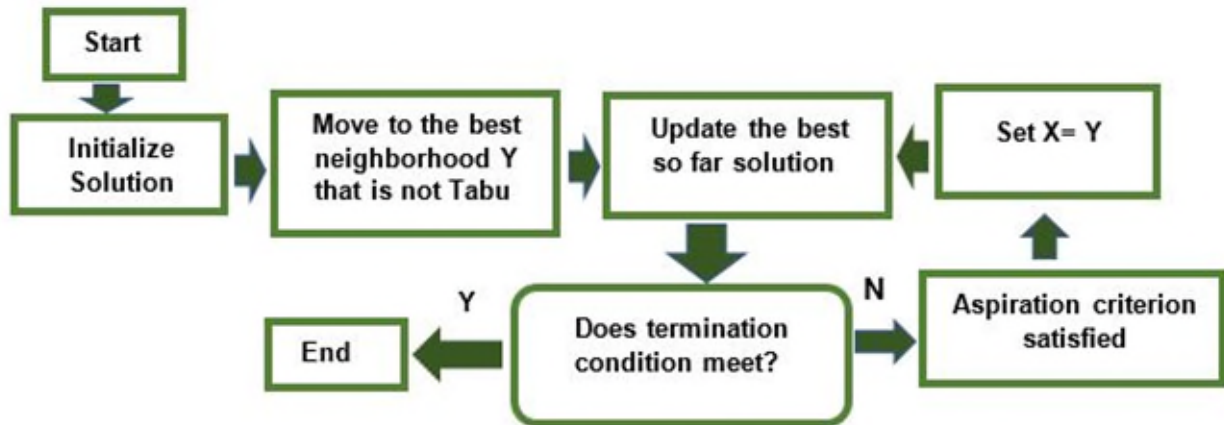
23 Introduction

24
25 In an effort to protect biodiversity, delineating protected areas, is a common strategy used by governments and
26 conservation agencies. With more than 35 million km² worldwide, these protected areas occupy 17% of the earth's
27 surface (IUCN 2022) where biodiversity is the focus of numerous conservation strategies (Kearney et al. 2020) making
28 these protected areas a helpful tool in supporting conservation of targeted taxa (Cox and Underwood 2011; Heringer
29 et al. 2020). However, globally managed protected areas do not adequately support endangered and rare species
30 (Rodrigues et al. 2004; Penjor et al. 2021). Economic and political considerations play a fundamental role in the
31 selection of the protected areas (Margules and Pressey 2000; Mehri et al. 2014), often in conflict with their ecological
32 values (Margules and Pressey 2000). For establishing conservation actions, there are often a variety of goals and
33 criteria, such as integrating protected areas into broader land management plan (Topal and Ongen 2006), mitigating
34 negative impacts on ecosystems (Smith et al. 2022), and connecting several protected areas (Saura et al. 2018). Within
35 the human dimension, all of these goals and criteria must take into account diverse interests and perspectives (Bennett
36 et al. 2017). Since protected areas are mostly located in places that do not comprehensively represent biodiversity,
37 most protected area networks have not successfully preserved essential biodiversity values (Margules and Pressey
38 2000; Mehri et al. 2014). One potential solution to this issue is systematic conservation planning which has been
39 applied to protected areas' prioritization worldwide (Smith et al. 2022). **Conservation planning is by nature data-**
40 **oriented and flexible. As such, systematic conservation planning approaches are based on a matrix of interactions**
41 **between environmental features and areas. In addition to a region's biodiversity, its geological and geomorphological**
42 **characteristics, as well as its functional characteristics (i.e. ecosystem services), can all be considered features. In**
43 **addition, areas that are evaluated for their contribution to conservation can be continuous (e.g. a whole watershed) or**
44 **discontinuous (e.g. parts of a forest ecosystem). The flexibility of conservation planning approaches thus require**
45 **flexibility with respect to available data and according to the desired conservation objectives. Ultimately, the**
46 **monitoring of conservation goals and the testing of conservation systems can be implemented through conservation**
47 **planning approaches (Pressey 1999).**

48 A systematic conservation planning approach includes site selection, design, and management of protected areas
49 that comprehensively represent biodiversity (Mehri et al. 2014). This approach has contributed to selecting
50 biodiversity rich protected areas in recent years (Pearce et al. 2008). Artificial intelligence-based methods that include
51 different computer algorithms to provide optimal solutions based on the definition of an objective function have been
52 one of the approaches in site selection (Game and Grantham 2008). Tabu search (Fig. 1) is one of the heuristic
53 algorithms used to optimize conservation area network spatial arrangement (Ciarleglio et al. 2010 a). The Tabu list
54 and aspiration criteria are two primary components of this algorithm. The former is a tool in the Tabu search algorithm
55 consisting of a set of rules used to filter the complete solution (Glover et al. 1993; Shadkam et al. 2021) while the
56 latter is used to override Tabu lists when, as the search progresses, several areas of the search space are listed as Tabu
57 based on their frequency (Glover et al. 1993; Lin and Miller 2004; Shadkam et al. 2021).

59

Fig. 1



60

Workflow of the Tabu search algorithm (Adapted from Glover et al., 1993).

61

62 Biodiversity is always region or ecosystem specific, and understanding species diversity requires an
63 understanding and quantification of the landscape structure (Walz, 2011). To this end, the use of landscape metrics
64 has been used to understand the relationships between landscape patterns and ecological characteristics (Chefaoui,
65 2014). Landscape composition and configuration can be quantified using several metrics (Gustafon, 1998; McGarigal
66 et al. 2012). The selection of appropriate landscape metrics depends on the purpose of the study as well as the
67 characteristics of the landscape and ecological process (Walz, 2011). In wildlife habitat studies, indicators such as
68 land use/cover types, and species richness are often applied to identify the most appropriate management practices for
69 restoring degraded habitats and sites of biodiversity significance (Pflüger and Balkenhol, 2014; Auffret et al. 2015).
70 However, Tabu's capabilities for optimizing protected areas have not been tested except hypothetically and
71 experimentally by the developers of the ConsNet software (Ciarleglio et al. 2009, Ciarleglio et al. 2010a, Ciarleglio
72 et al. 2010b). Moreover, although conservation planning using machine learning algorithms received much attention
73 in Iran (Mehri et al. 2014; Esfandeh et al. 2017; Nematollahi et al. 2022), the lack of studies on the prioritization of
74 biodiversity conservation networks based on analyzing landscape composition and configuration is quite apparent and
75 has affected the effective management of the protected area network. In this context, our study aims were to (1) assess
76 the capability of the Tabu search algorithm to optimize and prioritize suitable areas for conservation and (2) evaluate
77 the efficiency of the Hamedan Province protected area network based on landscape structure indicators. **Since
78 conservation planning is flexible and data driven, our approach can be widely used for various conservation purposes
79 at local, regional, national, and global scales. In addition, several types of data can be used, and experts in different
80 fields of conservation can thus benefit from this methodology to evaluate the features related to their fields.**

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86 **Methodology**

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88 Study Area

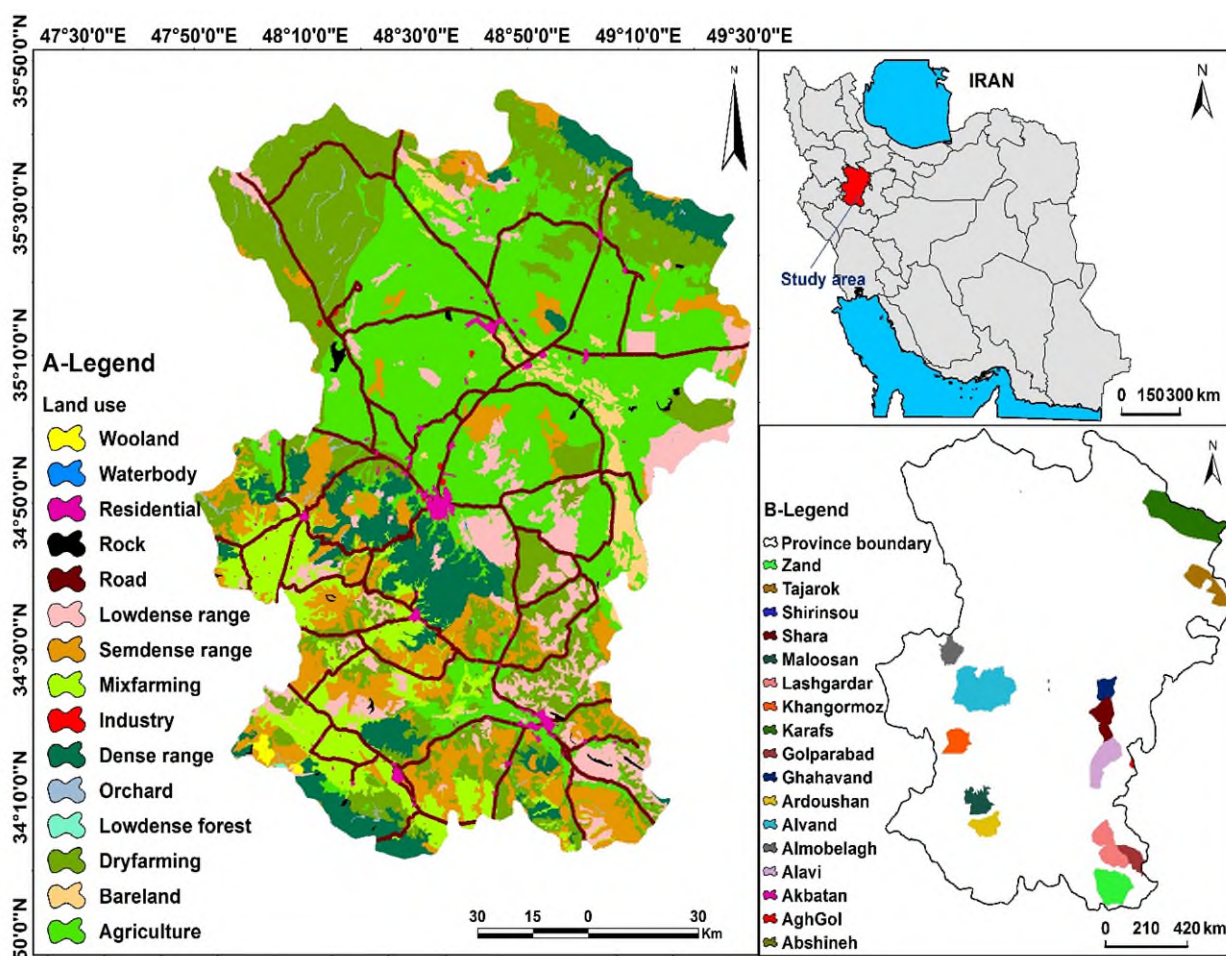
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90 Located west of Iran, Hamedan province is bordered by Zanjan, Qazvin, Lorestan, Markazi, Kurdistan, and
91 Kermanshah provinces. The region stretches between latitudes of 33° 59' and 35° 48' N and longitudes of 47° 44' and
92 49° 30' E. Hamedan has a cold and semi-arid climate with an average annual temperature of 11.5 °C and yearly
93 precipitation of 350 mm (Abdollahi et al. 2021). This region covers an area of 19491 km² (Fig. 2), of which
94 approximately 1300 km² (about 6.5%) includes plains, 5416 km² (27.8%) consists of plateaus and hills, and 3826 km²
95 (19.6%) of this region is covered by mountainous areas (Naderi-Mahdei and Bahrami, 2014). Hamedan province has
96 six protected areas: Golparabad, Khangormaz, Lashgardar, Shara, Almoblugh, Molusan, and nine no hunting areas of
97 Shirin Su, Alvand, Ghahavand, Abshineh wetland, Karafs, Alavi, Zand, Ekbatan wetland, and Aghogol (Abdollahi et
98 al., 2021). This province is habitat to more than 34 species of mammals (Karami et al., 2016) including wild sheep
99 (*Ovis orientalis*), wild goat (*Capra aegagrus*), brown bear (*Ursus arctos*), Eurasian lynx (*Lynx lynx*), Pale Bent-
100 winged Bat (*Miniopterus pallidus*), Wolf (*Canis lupus*), Grey Dwarf Hamster (*Cricetulus migratorius*) and Eurasian
101 Water Vole (*Arvicola amphibius*); 193 species of birds (Kaboli et al., 2016) including Egyptian vulture (*Neophron*
102 *percnopterus*), Eastern imperial eagle (*Aquila heliaca*), Saker falcon (*Falco cherrug*), and Eurasian hobby (*Falco*
103 *subbuteo*), White Stork (*Ciconia ciconia*), Garganey (*Anas querquedula*), Common Sandpiper (*Actitis hypoleucos*)
104 and Common Redshank (*Tringa totanus*); 45 species of reptiles (Mozaffari et al., 2016) including Asian snake-eyed
105 skink (*Ablepharus pannonicus*), mountain racerunner (*Eremias montana*), Persian toad-headed agama
106 (*Phrynocephalus persicus*) and Armenian viper (*Montivipera raddei*); 4 species of amphibians (Yousefi Siahkalroodi
107 et al., 2013) including Tree Frog (*Hyla savignyi*), Transcaucasian Frog (*Rana camerani*), Eurasian Marsh Frog
108 (*Pelophylax ridibundus*) and Common toad (*Bufo bufo*); and 1673 species of plants (Kolahi and Atari, 2014) including
109 Wild almond (*Amygdalus lycioides*), Aleppo oak (*Quercus infectoria*), Mountain Kakuti (*Ziziphora clinopodioides*)
110 and Medusa-head (*Taeniatherum crinitum*); among which 25 animal species and 34 plant species are endangered
111 (Abdollahi et al., 2021). In recent years, the province's protected areas have been deteriorating due to anthropogenic
112 activities such as urban development, conversion of natural lands to agricultural lands, and climate change (Soltani et
113 al. 2020).

114

115

Fig. 2



116

117 Geographical location of the research area; A- Land Use/ Land Cover (LULC) map, B- Hamedan protected
118 areas network.

119

Biodiversity Representatives

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121
122 The Tabu search algorithm was used to determine the prominent distribution regions for four bird species: the
123 Egyptian vulture (*Neophron percnopterus*), Eastern Imperial Eagle (*Aquila heliaca*), Saker Falcon (*Falco cherrug*),
124 and Eurasian Hobby (*Falco subbuteo*). In addition, the most suitable habitats for four mammal species were selected,
125 including the Eurasian lynx (*Lynx lynx*), brown bear (*Ursus arctos*), wild sheep (*Ovis orientalis*), and wild goat (*Capra*
126 *aegagrus*) as biodiversity representatives. These species were selected due to their protection status on Iranian hunting
127 and fishing laws, the International Union for Conservation of Nature (IUCN) Red List, and the CITES database of
128 species (Table 1). In addition, extensive information is available for them as they are important species in the region.

129 Habitat quality module in Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST;
130 <https://naturalcapitalproject.stanford.edu>) tool was used to generate basic habitat quality maps based on land use/
131 land cover (LULC) data and anthropogenic threats (Fig. 3).

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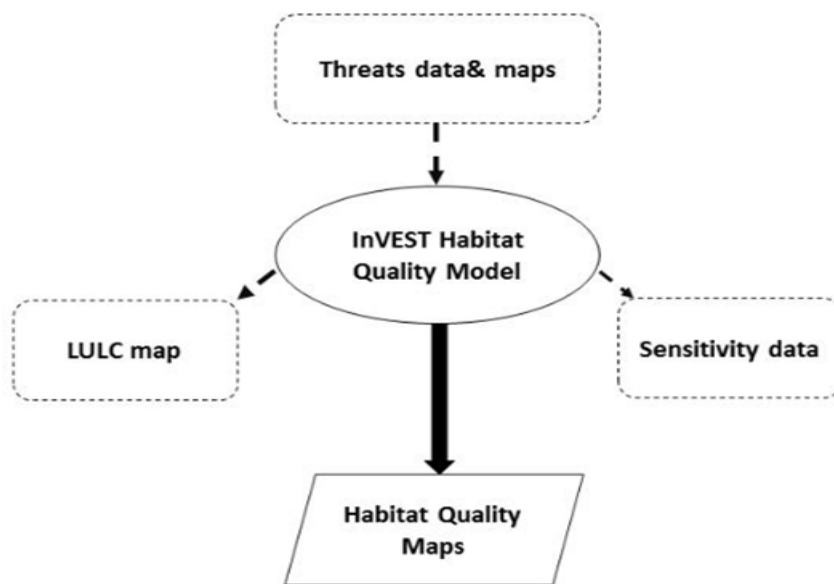
Table 1. Conservation status of selected biodiversity representatives.

Species	Conservation Status		
	IUCN	CITES	National Law
Eurasian lynx (<i>Lynx lynx</i>)	Least Concern (LC)	Appendix II	Endangered
Brown bear (<i>Ursus arctos</i>)	Least Concern (LC)	Appendix II	Protected
Wild sheep (<i>Ovis orientalis</i>)	Vulnerable (VU)	Appendix II	Protected
Wild goat (<i>Capra aegagrus</i>)	Vulnerable (VU)		Protected
Egyptian vulture (<i>Neophron percnopterus</i>)	Endangered (EN)		Protected
Eastern Imperial Eagle (<i>Aquila heliaca</i>)	Vulnerable (VU)	Appendix I	Endangered
Saker Falcon (<i>Falco cherrug</i>)	Endangered (EN)	Appendix II	Endangered (EN)
Eurasian Hobby (<i>Falco subbuteo</i>)	Least Concern (LC)	Appendix II	Protected

134

135

Fig. 3



136

137

InVEST Habitat Quality model framework (Adapted from Sharp et al. 2014).

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Invest model indicates that habitat quality is related to an ecosystem's ability to maintain an organism's survival; therefore, a high quality habitat supports greater biodiversity. The quality of the wildlife habitat will be adversely affected by large scale land use changes caused by human activities. An InVEST assessment of habitat quality is based on four parameters: the relative impact of threats, the relative sensitivity of each habitat type to a given threat, the distance between the source of threats and different habitats, and the degree of land protection (Sharp et al. 2014). Existing information (Asadolahi et al. 2018; Nematollahi et al. 2020; Li et al. 2021), InVEST manual (Sharp et al.

145 2014), and expert knowledge of the target area's characteristics were used to assign these data. We elicited twelve
146 academics and conservation officers who have good knowledge of wildlife ecology and the study area's characteristics
147 to score the threat sources from 0 to 1 based on the source's insensitivity (Supplementary Information, Tables SI 1,
148 and SI 2). Then, we selected the most suitable habitat zones based on zonal land suitability analysis and suitability
149 thresholds (Mehri et al. 2014; Mehri et al. 2018).

150

151 Prioritization of Protected Areas

152

153 ConsNet was used to prioritize and select candidate areas for biodiversity conservation (Ciarleglio et al. 2009). In this
154 software, various algorithms were employed to optimize protected area networks, including Tabu search, rarity search,
155 and supplemental algorithms. Although Tabu search takes longer to implement than other algorithms, it produces
156 more accurate and complete results. Providing multiple solutions, Tabu search allows users to search within the
157 decision space more efficiently (Ciarleglio et al. 2010 b). Here, only the Tabu search algorithm was used and the
158 search was defined following three conservation scenarios using the ConsNet software. In total, 3 input files were
159 used, including one mandatory file, one optional file of protected areas, and one optional restriction file. In the first
160 file, which served as the mandatory representative file, there were four components: the unique IDs of the cells, their
161 presence/absence data, their geographical location, and their costs. The cost is related to factors such as climate
162 conditions and geographical features that limit access to desirable habitats (Ciarleglio et al. 2010 b). Costs per cell can
163 be 0 (no cost) or 1 (a cost is associated with that cell). In this study, the cost was considered 0 because the information
164 was not accessible to us due to lack of cooperation among the relevant organizations. The second input file was related
165 to the existing protected areas and included information such as the cells of current protected areas and prohibited
166 hunting areas. The third file was the restriction file as each region has different restrictions for selecting protected
167 areas. The Road network was here considered as the restriction for biodiversity. Finally, the satisfaction factor
168 illustrates the reliability of the chosen solution. A satisfaction percentage is obtained based on the ratio of total
169 satisfaction to the number of cells indicating the presence of biodiversity representatives multiplied by 100. The higher
170 this factor is, the more acceptable the proposed solution is (Ciarleglio et al. 2010 b).

171

172 Conservation Scenarios

173

174 ConsNet was applied to generate three conservation scenarios in the study area. For all scenarios, the
175 conservation targets were to protect 10%, 20%, 25%, and 30% of the area of each biodiversity representative based
176 on Iran's Environmental Protection Organization, the Convention on Biological Diversity, and the number of
177 biodiversity representatives (Shams Esfandabad and Kaboli 2018). 500 repeat runs and 15×10⁶ iterations of the Tabu
178 search for all conservation goals were performed in ConsNet. In scenario 1, only the information included in the
179 mandatory representative file was used. In scenario 2, the mandatory representative file and the protected area file
180 were used. In scenario 3, the mandatory representative file and restriction file were used.

181

182 Evaluation of Conservation Patches Based on Landscape Criteria

183

184 The landscape composition and configuration metrics were selected based on their importance in ecological
 185 processes. The number and density of patches are associated to the terrain's structure without considering its spatial
 186 patterns while the Fractal Dimension Index (FRAC) and Contiguity Index (CONTG) metrics examine the spatial
 187 arrangement of landscape patterns. Therefore, various landscape metrics such as Number of Patches (NP), Patch
 188 Density (PD), Patch Area Distribution (AREA_MN), Contiguity Index, Perimeter Area Ratio Distribution (PARA),
 189 Euclidean Nearest Neighbor Distance (ENN), Landscape Shape Index (LSI), Fractal Dimension Index, and Effective
 190 Mesh Size (MESH) at the class level were calculated to evaluate and compare the shape complexity, and compactness
 191 of the selected conservation patches (Gustafon 1998; McGarigal et al. 2012, Table 2). This was accomplished by
 192 importing the maps produced in the previous step as an input layer into Fragstats software version 4.2 (McGarigal et
 193 al. 2012).

194

195 **Table 2.** Description of selected landscape metrics at class level which various aspects of landscape
 196 appearance are measured by these metrics, including habitat density, number, and continuity (McGarigal et al.
 197 2012).

198

Landscape indices (abbreviation)	Description	Unit	References
NP	Number of each patch type (class level)	No unit	Morelli and Tryjanowski (2014)
PD	Length of all patch edges divided by the patch area	0.01 km ²	Martínez-Ruiz et al. (2020)
AREA_MN	The mean area of each patch type (class)	Hectare	Michalski and Peres (2017)
CONTIG	The degree of each patch type proximity	Meter	Song and Kim (2016)
PARA_MN	The average ratio of each patch type perimeter to its area	No unit	Schindler et al. (2013) Pagaldai et al. (2021)
ENN_MN	The average distance between patches of the same class indicating how isolated they are	Meter	Moulatlet et al. (2021)
LSI	The shape index of the land calculated by dividing the total length of the patches' borders by the total area of the patches	No unit	
FRAC	The sum of all patches corresponding to the patches' value divided by the number of patches of the same type	No unit	Schindler et al. (2013)
MESH	A relative quantity of patch structure based on cell size	Hectare	Mairota et al. (2013)

199

200

201

202 Data Analysis

203

204 To determine if the variables were normally distributed, a Kolmogorov Smirnov test was performed on all
205 variables due to the small sample size for some of them (Godinho and Rabaça, 2011). Canoco v.5 was used to
206 investigate the associations between landscape parameters and conservation targets. Detrended canonical
207 correspondence analysis (DCCA) was used to recognize the appropriate ordination approach. A linear model was
208 applied to the measured gradient length and a redundancy analysis (RDA) was conducted to explore the associations
209 between landscape patterns and conservation targets in the study area. The significance of the DCCA approach was
210 assessed based on 999 Monte Carlo permutations.

211

212 **Results**

213

214 Conservation Network Prioritization

215

216 The Tabu search algorithm produced different results for the three defined scenarios, depending on the model
217 parameters. In scenario 1, the minimum and maximum values for total biodiversity representative were 191772 and
218 315530 hectares, respectively (Table 3). As conservation targets were set higher, the Tabu search algorithm proposed
219 a higher level of satisfaction. A maximum of 92% was achieved for the protection of 30% of the area of biodiversity
220 representatives. The mammal and bird species considered in our study represented a high conservation value at the
221 national and regional levels. However, the current protected areas represented insufficient habitat for these species
222 (Fig. 4). Approximately 19177.2 hectares of the 191882.68 hectares covered habitats of the target species,
223 representing only 10% of the total area for biodiversity protection (Table 3).

224

225 **Table 3.** Tabu search for scenario 1.

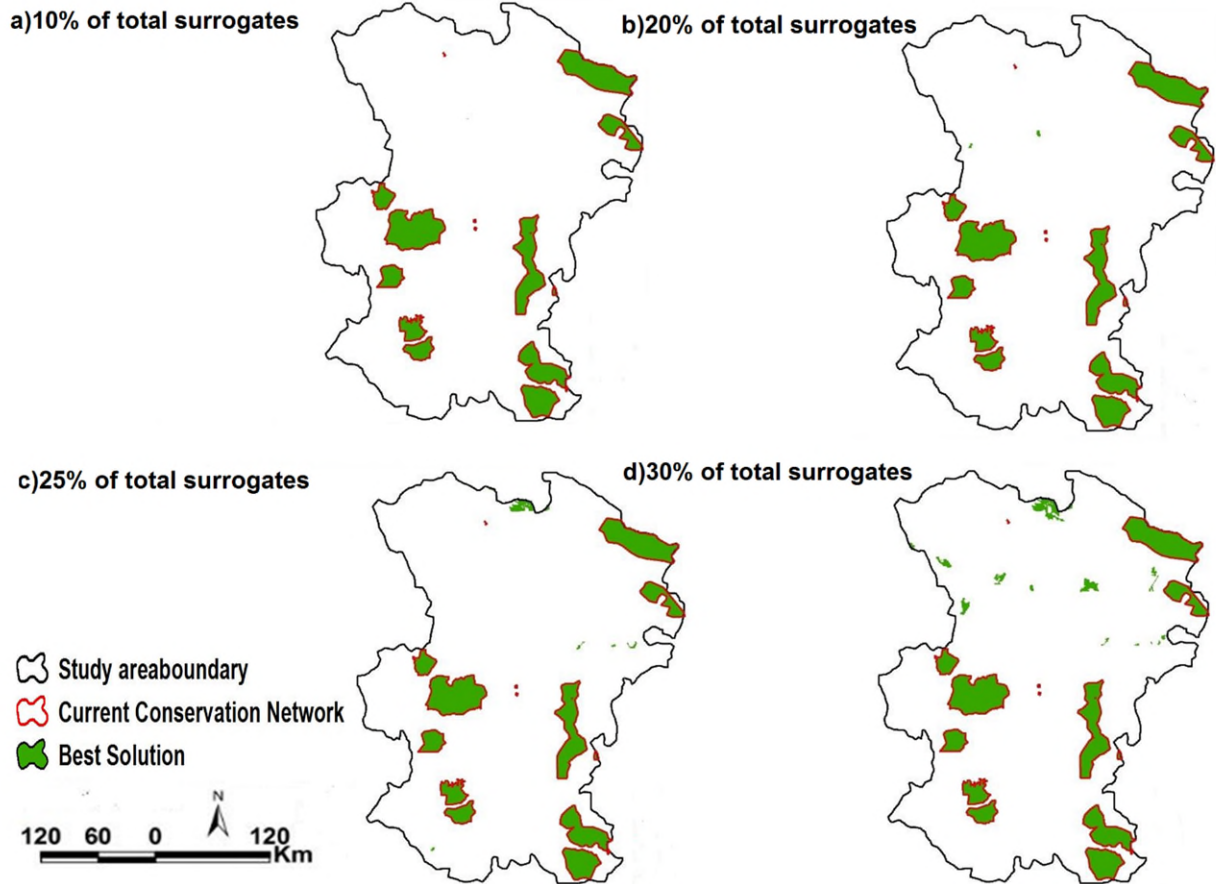
226

Conservation Targets %	Number of Clusters	Total Biodiversity Representation (number of solution cells)	Area (ha)	Perimeter (Km)	Total Satisfied
10	19	2587200	191772	933.6	0.84
20	21	2637600	192420	951.6	0.90
25	30	2787700	197802	1071	0.90
30	45	3155300	209664	1317.6	0.92

227

228

Fig. 4



230

231 Recommended conservation networks based on scenario 1. The red area represent the current protected areas,
 232 and the green areas represent the supplemental areas recommended for conservation as a result of the ConsNet.

233

234 For scenario 2, the minimum and maximum recorded values for total biodiversity representation comprised
 235 189324, 190035, 195372, and 202716 hectares, representing 9.7, 9.75, 10.024, and 10.4% of the province, for the
 236 different conservation targets respectively (Table 4). The road network constraint reduced the extent needed to achieve
 237 the conservation targets in scenario 3 compared to other scenarios (Fig. 5).

238

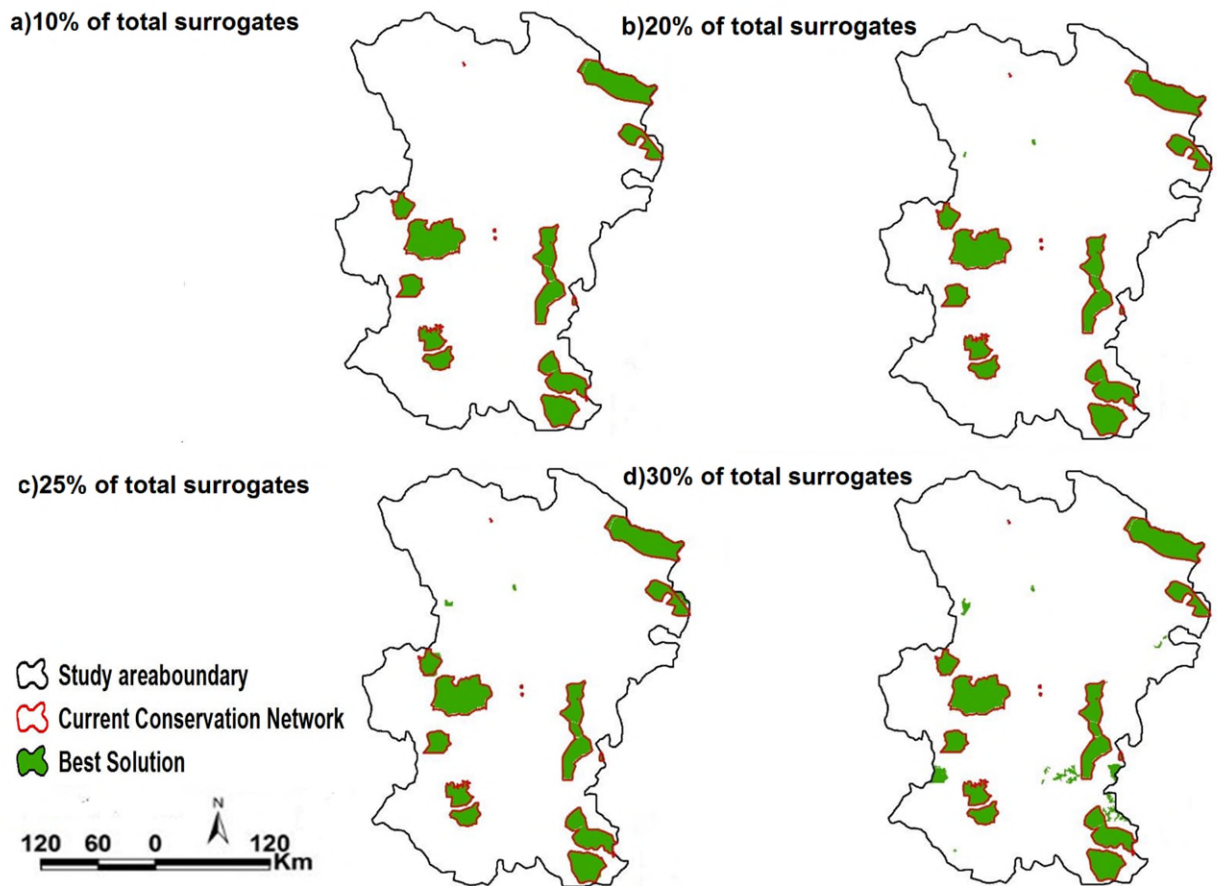
239 **Table 4.** Tabu search for scenario 2.

240

Conservation Targets %	Number of Clusters	Total Biodiversity Representation (number of solution cells)	Area (ha)	Perimeter (km)	Total Satisfied
10	66	2587700	189324	1081.8	0.74
20	70	2637800	190035	1099.2	0.76
25	72	2787700	195372	1103.4	0.87
30	84	3140400	202716	1476.6	0.93

241

242 **Fig. 5**



243

244 Recommended conservation networks based on scenario 2. The red area represent the current protected areas,
 245 and the green areas represent the supplemental areas recommended for conservation as a result of the ConsNet.

246

247 Under the third scenario, the minimum and maximum recorded values for total biodiversity representation were
 248 45873 hectares and 14617.8 hectares, respectively (Table 5). Compared to the previous two scenarios, the conservation
 249 patches selected according to different conservation objectives were smaller. Of the Hamedan province, 2.3, 4.9, 6.2,
 250 and 7.5% of protected areas have been chosen for the protection of 10, 20, 25, and 30 % of the total area for biodiversity

251 representatives (Fig. 6). In scenario 3, the perimeter and area of the selected network increased as the conservation
 252 target increased (Table 5).

253

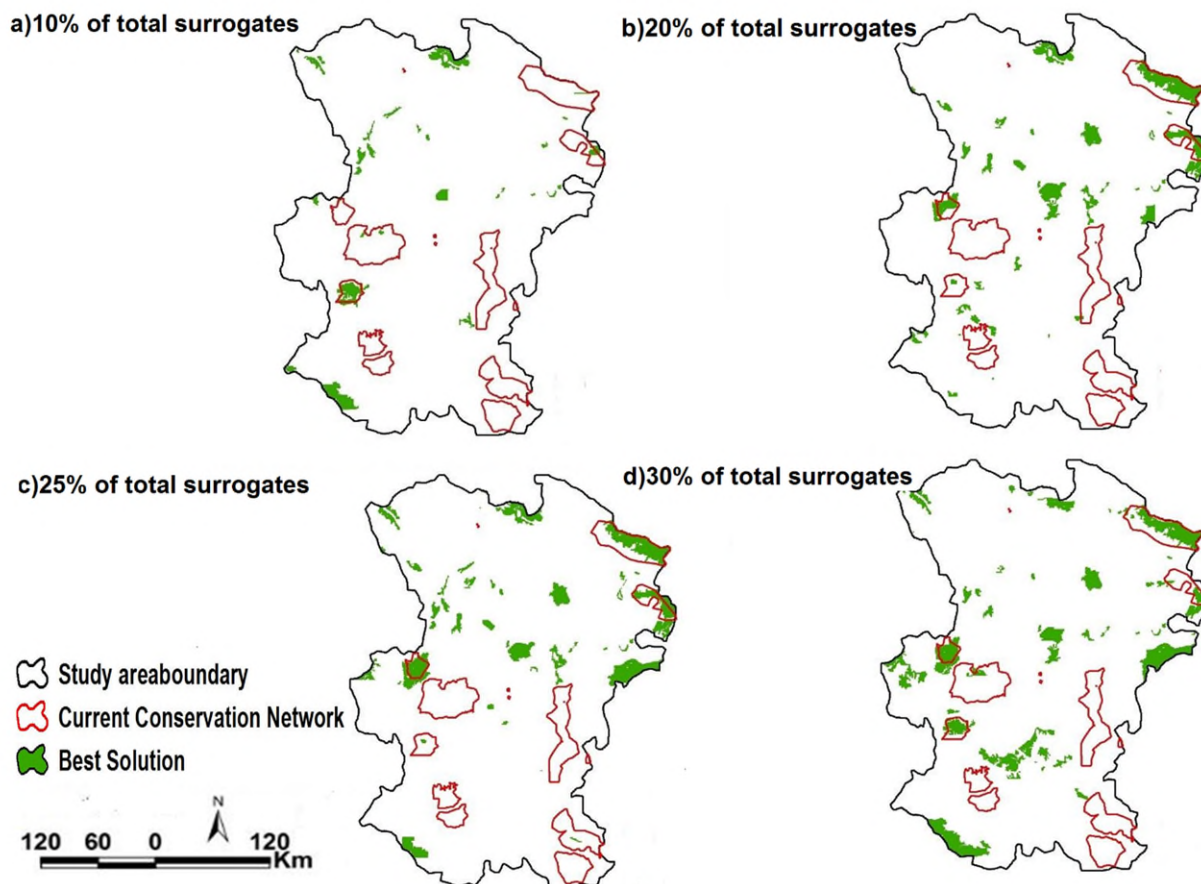
254 **Table 5.** Tabu search for scenario 3.

255

Conservation Targets %	Number of Clusters	Total Biodiversity Representation (number of solution cells)	Area (ha)	Perimeter (km)	Total Satisfied
10	30	1131600	45873	759.6	0.86
20	41	2085300	96012	1270.8	0.94
25	53	2579400	1210.4	1543.2	0.95
30	55	3133400	14617.8	1895.4	0.93

256

257 **Fig. 6**



258

259 Recommended conservation networks only based on biodiversity representative's distribution. The red area
 260 represent the current protected areas, and the green areas represent the supplemental areas recommended for
 261 conservation as a result of the ConsNet.

262

263 Analyzing Conservation Patches Using Landscape Indices

264

265 With increase of the number of conservation patches (NP) in all three scenarios, the protection of biodiversity
 266 representatives in the target area increased (Table 6). In all three scenarios with increasing conservation targets, patch
 267 density (PD) has also increased, indicating a dispersion of conservation patches. In all scenarios, the LSI index showed
 268 almost the same pattern (Table 6). Although the number and density of patches have increased in both scenarios 1 and
 269 2, the AREA_MN showed a declining trend. However, this index has raised slightly in scenario 3. For all conservation
 270 targets in the first and third scenarios, the value of CONTIG was 0.7 on average, indicating that conservation patches
 271 are relatively close together. The second scenario showed an average continuity of conservation patches of 0.5 for all
 272 conservation targets. In both scenario 1 and 2, the PARA_MN index had the highest values for protection of 10% of
 273 biodiversity representatives, however, in the third scenario, the greatest value was for the protection of 25% of
 274 biodiversity representatives (Table 6). The value of ENN_MN index for the protection of 20% of biodiversity
 275 representatives was greater than other conservation targets in the first and second scenarios, whereas in the third
 276 scenario, it was greater than other conservation targets for the protection of 10% of biodiversity representatives (Table
 277 6). Scenario 1 had an increasing FRAC index. It was observed that scenarios 2 and 3 had a higher index value, with
 278 30% and 25%, respectively, of biodiversity representatives being protected (Table 6). In the first and second scenarios,
 279 MESH was roughly at the same level and very close together with a slight decrease, indicating that the patches were
 280 close together, whereas, in the third scenario, it showed an increasing trend (Table 6).

281

282 **Table 6.** The result of the landscape metrics analysis in 3 different scenarios. Acronyms are defined in table 2.

Landscape metrics	Scenario 1				Scenario 2				Scenario 3			
	10%	20%	25%	30%	10%	20%	25%	30%	10%	20%	25%	30%
NP	16	17	22	31	24	26	26	34	29	37	42	48
PD	750.82	795.136	1001	1330.7	1140.4	1231.3	1197.7	1476.72	5689.62	3467.9	3121.29	2955.3
AREA_MN	0.1332	0.1258	0.0999	0.0751	0.0877	0.0812	0.0835	0.0677	0.0176	0.0288	0.032	0.0338
CONTIG	0.725	0.771	0.745	0.733	0.504	0.524	0.528	0.586	0.763	0.789	0.76	0.764
PARA_MN	10809.05	8836.46	9699.06	9940.76	19150.6	18285.8	18136.93	15873.04	8268.27	7315.98	8426.32	8194.35
ENN_MN	18.065	21.331	17.12	18.019	8.116	14.272	13.67	13.252	29.589	26.157	23.765	13.732
LSI	5.336	5.413	6.01	7.176	6.196	6.29	6.234	8.095	8.85	10.174	11.09	12.39
FRAC	1.174	1.18	1.228	1.248	1.121	1.118	1.117	1.200	1.24	1.218	1.26	1.24
MESH	0.2815	0.2806	0.274	0.261	0.276	0.275	0.275	0.267	0.059	0.095	0.1069	0.1134

283

284

285 Association Evaluation

286

287 According to the RDA results, there was a correlation between landscape metrics and conservation targets in
 288 the study area (Table 7). The first two axes of this analysis explained 59.71 and 19.94% of total landscape indices

289 variation, respectively. The correlation between conservation targets and landscape metrics was 93 and 92% for the
 290 two first axes indicating the effectiveness of landscape parameters on conservation targets variation.

291

292 **Table 7.** Association results between conservation targets and landscape metrics.

293

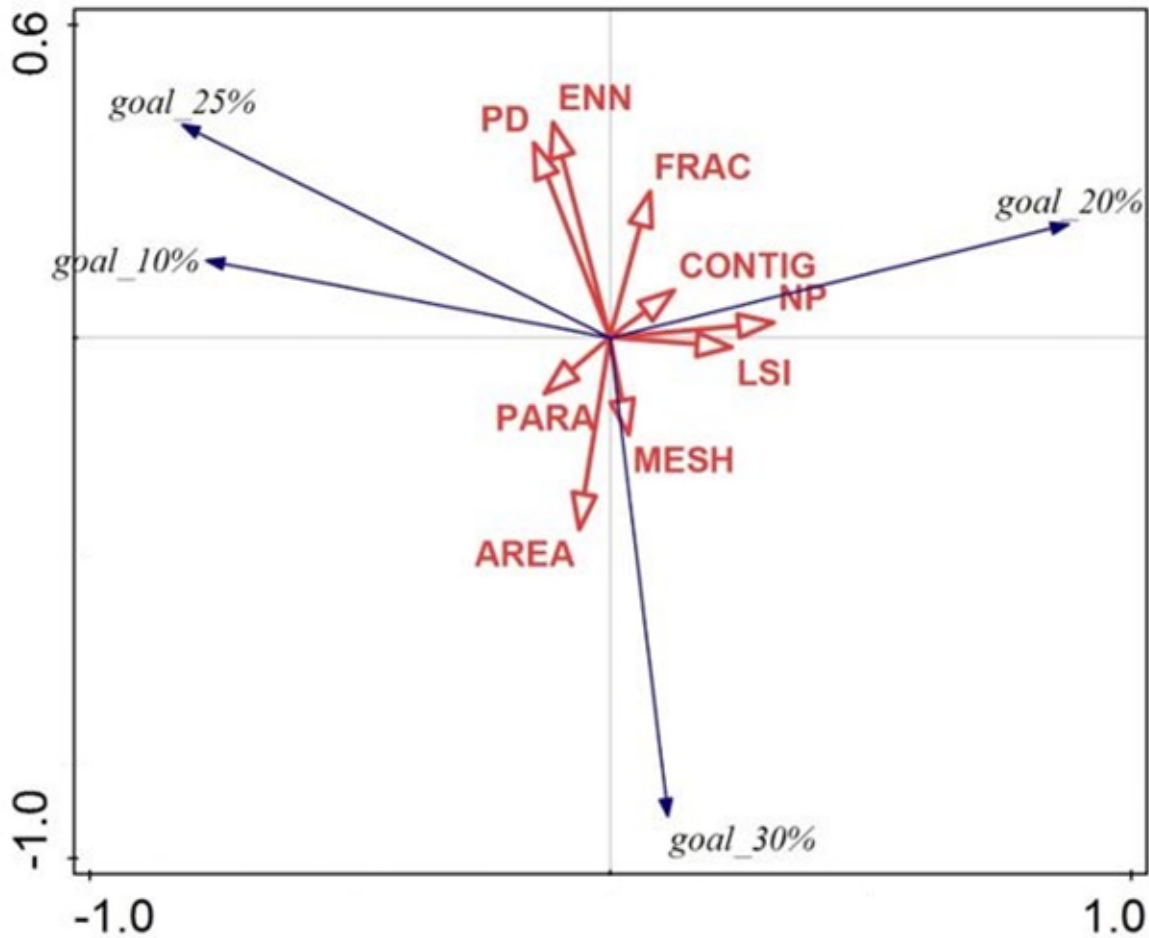
Statistic	Axes				Sum
	1	2	3	4	1
Eigenvalues	0.5971	0.1994	0.0436	0.1225	
Correlation between conservation targets and landscape parameters	0.933	0.919	0.747	0.000	
Cumulative variation for landscape parameters	59.71	79.65	84.01	96.26	
Cumulative variance percentage of the relationship between conservation goals and landscape parameters	71.08	94.81	100.00		
All eigenvalues					1
Canonical eigenvalues			0.840		

294

295 Two groups of landscape metrics were distinguished (Fig. 7). The first group included FRAC_MN, CONTIG,
 296 NP, LSI, and MESH and all indices except MESH indicated a positive correlation with the protection of 20% of total
 297 biodiversity representatives, while other conservation targets were negatively correlated with them. The second group
 298 involved ENN_MN, PD, AREA_MN, and PARA. ENN_MN and PD in this group positively correlated with the
 299 protection of 10 and 25% of total biodiversity representatives, while AREA_MN and PARA represented a negative
 300 correlation with these conservation targets. The protection of 30% of total biodiversity representatives showed a
 301 positive correlation with PARA, AREA_MN, and MESH, and a negative correlation with other landscape metrics.
 302 Among all metrics, PD, ENN_MN, and AREA_MN showed the highest correlation with conservation targets.

303

304 Fig. 7



305
306 RDA ordination on conservation targets and landscape metrics.

307
308 **Discussion**

309
310 In this study, ConsNet was used for prioritizing and selecting candidate areas for biodiversity conservation in
311 Hamedan Province. In considering the efficiency of current protected areas, it was found that these areas are not
312 sufficient to attain conservation targets and only protect 10% of the total area of each biodiversity representative. Our
313 results are consistent with previous studies (Jafari et al. 2011; Momeni Dehaghi et al. 2013; Mehri et al. 2014;
314 Esfandeh et al. 2017; Boulad et al. 2022), describing inadequately protected area networks. According to scenario 1,
315 the protection network would be substantially increased, along with conservation targets. However, this is not possible
316 in the short term due to high levels of infrastructure and economic development in Hamedan province, including
317 mining. Thus, it is recommended that the ConsNet solution for scenario 1 be reviewed as a long term solution to
318 complete the conservation targets and future strategies of the Environmental Protection Organization of Iran in
319 Hemadan province. Based on national conservation plans, it should be updated to protect 17% of the total biodiversity
320 hotspots (Shams esfandabad and Kaboli, 2018). ConsNet solution for scenario 3 is based only on the presence data of

321 biodiversity representatives in the target area, and this scenario included less area for different conservation targets
322 than the two other scenarios to achieve the best solution for protecting the most biodiversity representatives at the
323 minimum possible area. Furthermore, the selected conservation network has minimal overlap with the current network
324 of protected areas, which emphasizes the inefficiency of the current protected areas network in protecting biodiversity
325 representatives in the target area.

326 Comparing the different scenarios, scenario 1 with 90% representation satisfied protects 25% of total biodiversity
327 representatives. This is the most effective solution, covering 10.14% of Hamedan province and is an ideal alternative
328 to achieving global conservation targets (preserving 10% of each region). In addition, the total satisfaction includes
329 an acceptable result for conservation targets in three scenarios (Tables 2, 3 and 4) to evaluate the selected protected
330 areas network, indicating that a range of solutions could be used to meet conservation targets (Leslie et al. 2003; Mehri
331 et al. 2014). Having a variety of solutions allows planners to select the best alternative based on ecological, economic,
332 social, political, and other factors (Mehri et al. 2014; Possingham et al. 2000). In different scenarios and conservation
333 targets, the biodiversity representative shows more than 70% of the total satisfied, suggesting that the Tabu search
334 algorithm is highly accurate in evaluating protected areas. Regardless of the differences in solutions presented in the
335 studied scenarios, they all highlight the need to expand and alter the boundaries of current protected areas in Hamedan
336 province to achieve conservation targets (Boulad et al. 2022). In Iran, similar studies have shown that systematic
337 conservation planning with a high degree of flexibility can help apply scientific principles and criteria at the national
338 level and be used to adopt conservation criteria at a large scale (Mehri et al. 2014; Jafari et al. 2011; Esfandeh et al.
339 2017).

340 The spatial arrangement of a landscape (e.g., the density and cohesion of habitat patches) has significant impacts
341 on biodiversity. Landscape metrics and can be used in wildlife habitat suitability analyses (Calamari et al. 2018; Reis
342 et al. 2021), particularly for the distribution of conservation patches for conservation planning and management
343 (Botequilha et al. 2006). Reduced patches contribute less to biodiversity protection as their density decreases (Norton
344 et al. 2016; Spiesman et al. 2018) and according to our results, patches with more cohesion and compaction have a
345 higher conservation value. Increasing the perimeter-to-area ratio for the conservation patches also negatively affects
346 the species' survival. By increasing habitat edges, biodiversity is more vulnerable to existing threats which, in the long
347 run, reduces biodiversity levels at protected area borders (Fagan et al. 1999). Based on the evaluation of landscape
348 metrics, the number and density of conservation patches have increased in Hamedan province. This change is due to
349 the unbalanced development of industrial and residential areas, indicating a dispersion of landscape patterns in this
350 province and causing more fragmentation of the selected protected areas (Shayesteh and Mohammadyary, 2018).
351 Small patches of fragmented conservation indicate the fine scale structure of selected protected patches. A fragmented
352 landscape tends to be more complex and irregular, exhibiting little structural integrity (Wintle et al. 2019). The
353 Euclidean Nearest Neighbor Distance index showed that the values of this metric were relatively low for selected
354 conservation patches in Hemadan province. When a landscape is fragmented, it tends to be complex and irregular,
355 exhibiting little structural integrity. Hence, the distribution pattern of protected areas in the province is dispersed. The
356 remoteness of conservation patches increases planning and management costs, and also negatively impacts the region's
357 ecological sustainability (Sadegh Oghli et al. 2019).

358 Results of RDA also confirmed our results of conservation targets based on landscape metrics. ENN_MN, PD,
359 and AREA_MN involve the highest correlation with conservation targets and indicate the fragmentation of patches.
360 Existing studies (e.g. Battisti 2003; Chetcuti et al. 2020; Flowers et al. 2020) have highlighted that habitat
361 fragmentation contributes significantly to biodiversity loss. Therefore, to prevent biodiversity loss and achieve
362 conservation goals, it is important to manage protected areas so that habitat fragmentation is minimized.

363

364 **Conclusion**

365

366 In this study, a meta-heuristic algorithm along with a landscape ecology approach were applied to optimize the
367 conservation network of the Hamedan province in Iran. Accordingly, three scenarios were defined for optimizing the
368 conservation network of the target area based on protecting 10%, 20%, 25%, and 30% of the area for biodiversity
369 surrogates. With 90% representation satisfied protecting 25% of total biodiversity representatives, scenario 1 was the
370 most effective solution, covering 10.14% of Hamedan province and therefore approaching global conservation targets.
371 The results of this study demonstrate the capability and value of landscape metrics for evaluating and managing
372 protected areas and identifying conservation patches. Thus, models, tools, and spatial data can assist in assessing,
373 managing, and planning the protected area network and enhancing biodiversity. Landscape structural changes can be
374 an effective strategy for conducting more detailed studies and determining practical conservation actions. Therefore,
375 land use planners and managers can use the results of this study to align conservation and management strategies to
376 maximize biodiversity conservation. Overall, our conservation planning approach reflects certain quantitative goals
377 such as the long-term management of protected areas, and thus these approaches can be used indefinitely and at low
378 cost for the management of different areas with different characteristics.

379

380 **References**

- 381 Abdollahi S, Ildoromi A, Shayesteh K (2021) Ranking of Protected Areas of the Hamedan Province based on
382 Conservation Criteria. *Hum. Environ* 19: 35-47 (In Persian).
- 383 Asadolahi Z, Salmanmahini A, Sakieh Y, Mirkarimi SH, Baral H, Azimi M (2018) Dynamic trade-off analysis
384 of multiple ecosystem services under land-use change scenarios: Towards putting ecosystem services into
385 planning in Iran. *Ecol. Complex* 36: 250- 260. <https://doi.org/10.1016/j.ecocom.2018.09.003>
- 386 Auffret AG, Plue J, Cousins SAO (2015) The spatial and temporal components of functional connectivity in
387 fragmented landscapes. *Ambio* 44: 51–59. <https://doi.org/10.1007/s13280-014-0588-6>
- 388 Battisti C, (2003) Habitat fragmentation, fauna and ecological network planning: Toward a theoretical
389 conceptual framework. *Ital. J. Zool* 70: 241-247. <https://doi.org/10.1080/11250000309356524>
- 390 Bennett NJ, Roth R, Klain SC, Chan K, Christie P et al (2017) Conservation social science: Understanding and
391 integrating human dimensions to improve conservation. *Biol. Conserv* 205: 93-108.
392 <https://doi.org/10.1016/j.biocon.2016.10.006>
- 393 Botequilha AL, Miller J, Ahren J, McGarigal K (2006) *Measuring Landscape, A planner Handbook*. Island
394 Press, Washington DC.
- 395 Boulad N, Al-Shogoor S, Sahwan W, Al-Ouran N, Schütt B (2022) Systematic Conservation Planning as a Tool
396 for the Assessment of Protected Areas Network in Jordan. *Land* 11: 56.
397 <https://doi.org/10.3390/land11010056>
- 398 Calamari NC, Vilella FJ, Sica YV, Mercuri PA (2018) Patch and landscape responses of bird abundance to
399 fragmentation in agroecosystems of east-central Argentina. *ACE* 13:3. [https://doi.org/10.5751/ACE-01222-](https://doi.org/10.5751/ACE-01222-130203)
400 130203
- 401 Chefaoui RM (2014) Landscape metrics as indicators of coastal morphology: a multiscale approach. *Ecol. Indic*
402 45:139–147. <https://doi.org/10.1016/j.ecolind.2014.04.004>
- 403 Chetcuti J, Kunin WE, Bullock JM (2020) Habitat fragmentation increases overall richness, but not of habitat-
404 dependent species. *Front. Ecol. Evol* 8: 12. 607619. <https://doi.org/10.3389/fevo.2020.607619>
- 405 Ciarleglio M, Barnes JW, Sarkar S (2009) ConsNet: new software for the selection of conservation area
406 networks with spatial and multi-criteria analyses. *Ecography* 32: 205-209. [https://doi.org/10.1111/j.1600-](https://doi.org/10.1111/j.1600-0587.2008.05721.x)
407 0587.2008.05721.x
- 408 Ciarleglio M, Barnes JW, Sarkar S (2010 a) ConsNet-A tabu search approach to the spatially coherent
409 conservation area network design problem. *Heuristics* 16: 537-557. [https://doi.org/10.1007/s10732-008-](https://doi.org/10.1007/s10732-008-9098-7)
410 9098-7
- 411 Ciarleglio M, Sarkar S, Barnes JW (2010 b) *ConsNet User Manual Version 2.00*. Biodiversity and Biocultural
412 Conservation Laboratory, Section of Integrative Biology, 1 University Station, C0390, and the University
413 of Texas at Austin. Austin TX 78712, Available: [http://uts.cc.utexas.edu/~consbio/](http://uts.cc.utexas.edu/~consbio/Cons/consnet_home.html)
414 Cons/consnet_home.html.
- 415 Cox RL, Underwood E C (2011) The Importance of Conserving Biodiversity Outside of Protected Areas in
416 Mediterranean Ecosystems. *PLoS One* 6: e14508. <https://doi.org/10.1371/journal.pone.0014508>

417 Esfandeh S, Kaboli M, Eslami L (2017) Simulated annealing algorithm as a tool for systematic prioritization of
418 protected area in Alborz province, Iran. *J. Anim. Environ* 9:105-122 (In Persian).
419 <https://doi.org/10.1001.1.27171388.1396.9.1.14.0>

420 Fagan WF, Cantrell RS, Cosner C (1999) How Habitat Edges Change Species Interactions. *Am. Nat* 153: 165-
421 182. <https://doi.org/10.1086/303162>

422 Flowers B, Huang KT, Aldana GO (2020) Analysis of the Habitat Fragmentation of Ecosystems in Belize Using
423 Landscape Metrics. *Sustainability* 12: 3024. <https://doi.org/10.3390/su12073024>

424 Game ET, Grantham HS (2008) Marxan user manual: For Marxan version 1.8.10. St. Lucia, Queensland,
425 Australia/Vancouver, British Columbia, Canada: University of Queensland/Pacific Marine Analysis and
426 Research Association. www.ecology.uq.edu.au/marxan.htm.

427 Glover F, Taillard E, Taillard E (1993) A user's guide to tabu search. *Ann. Oper. Res* 41: 1–28.
428 <http://dx.doi.org/10.1007/BF02078647>

429 Godinho C, Rabaça J E (2011) Birds like it Corky: the influence of habitat features and management of
430 ‘montados’ in breeding bird communities. *Agroforestry Systems*, 82, 183-195.

431 Gustafson EJ (1998) Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems* 1: 143–156.
432 <http://dx.doi.org/10.1007/s100219900011>

433 Heringer G, Almeida TE, de Oliveira Dittrich VA, Salino A (2020) Assessing the effectiveness of protected
434 areas for the conservation of ferns and lycophytes in the Brazilian state of Minas Gerais. *J. Nat. Conserv*
435 53: 125775. <https://doi.org/10.1016/j.jnc.2019.125775>

436 IUCN (2022) World Database on Protected Areas, <https://www.iucn.org/our-work/protected-areas-and-land-use>,
437 online available June 26th.

438 Jafari A, Yavari A, Bahrami S, Yarali N (2011) Selection of new protected areas emphasizing vegetation types
439 using C-Plan (case study: Kohgiluyeh & Boir-Ahmad province, Iran). *J. Environ. Stud* 36: 1–12 (In Persian).

440 Kaboli M, Aliabadian M, Tohidifar M, Hashemi A, Musavi S B, Roselaar C C (2016) The Atlas of Birds of Iran
441 (1st ed.) Academic Center for Education, Culture and Research Kharazmi branch Press. Karaj, Iran, 628 pp
442 (In Persian)

443 Karami M, Ghadierian T, Faizolahi K (2016) Atlas of Iranian Mammals, (1st ed.) Academic Center for
444 Education, Culture and Research Kharazmi branch Press. Karaj, Iran, 292 pp (In Persian).

445 Kearney S, Adams V, Fuller R, Possingham H, Watson J (2020) Estimating the benefit of well-managed
446 protected areas for threatened species conservation. *Oryx* 54: 276-284.
447 <http://dx.doi.org/10.1017/S0030605317001739>

448 Kolahi M, Atri M (2014) Plant Diversity, Life Form and Phytochoria of Hamedan Alvand Region in Iran. *oalib*
449 1: e682.

450 Leslie H, Ruckelshaus M, Ball IR, Andelman S, Possingham P H (2003) Using siting algorithms in the design of
451 marine reserve networks. *Ecol Appl* 13: 185–198. <https://www.jstor.org/stable/3100007>

452 Li M, Zhou Y, Xiao P, Tian Y, Huang H, Xiao L (2021) Evolution of Habitat Quality and Its Topographic
453 Gradient Effect in Northwest Hubei Province from 2000 to 2020 Based on the InVEST Model. *Land* 10:
454 857. <https://doi.org/10.3390/land10080857>

455 Lin B, Miller DC (2004) Tabu search algorithm for chemical process optimization. *Comput Chem Eng* 28: 2287-
456 2306. <https://doi.org/10.1016/j.compchemeng.2004.04.007>

457 Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* 405: 243–253.

458 McGarigal K, Cushman SA, Ene E (2012) FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical
459 and Continuous Maps. Computer software program produced by the authors at the University of
460 Massachusetts, Amherst, Available at <http://www.umass.edu/landeco/research/fragstats/fragstats>

461 Mehri A, Salmanmahiny A, Mirkarimi SH, Rezaei HR (2014) Use of optimization algorithms to prioritize
462 protected areas in Mazandaran Province of Iran. *J. Nat. Conserv* 22: 462-470.
463 <https://doi.org/10.1016/j.jnc.2014.05.002>

464 Mehri A, Salmanmahiny A, Mikaeili Tabrizi AR, Mirkarimi SH, Sadoddin A (2018) Integration of
465 anthropogenic threats and biodiversity value to identify critical sites for biodiversity conservation. *Geocarto*
466 *Int* 34:1202-1217. <https://doi.org/10.1080/10106049.2018.1475510>

467 Mairota P, Cafarelli B, Boccaccio L, Leronni V, Labadessa R, Kosmidou V, Nagendra H (2013) Using
468 landscape structure to develop quantitative baselines for protected area monitoring. *Ecol. Indic* 33: 82-95.
469 <https://doi.org/10.1016/j.ecolind.2012.08.017>

470 Martínez-Ruiz M, Arroyo-Rodríguez V, Franch-Pardo I, Renton K (2020) Patterns and drivers of the scale of
471 effect of landscape structure on diurnal raptors in a fragmented tropical dry forest. *Landsc. Ecol* 35: 1309–
472 1322. <https://doi.org/10.1007/s10980-020-01016-6>.

473 Michalski F, Peres CA (2017) Gamebird responses to anthropogenic forest fragmentation and degradation in a
474 southern Amazonian landscape. *Peer J* 5: e3442. <https://doi.org/10.7717/peerj.3442>

475 Momeni Dehaghi I, Salmanmahini A, Alizadeh Shabani A, Karami M (2013) Efficiency of current reserve
476 network in Golestan Province (Iran) for the protection of hoofed ungulates. *Biodiversity* 14:162-168.
477 <https://doi.org/10.1080/14888386.2013.805659>

478 Morelli F, Pruscini F, Santolini R, Perna P, Benedetti Y, Sisti D (2013) Landscape heterogeneity metrics as
479 indicators of bird diversity: Determining the optimal spatial scales in different landscapes. *Ecol. Ind* 34:
480 372–379. <https://doi.org/10.1016/j.ecolind.2013.05.021>

481 Moulatlet GM, Ambriz E, Guevara J, Lopez KG, Rodes-Blanco M, Guerra-Arevalo N, Ortega-Andrade HM,
482 Menses P (2021) Multi-taxa ecological responses to habitat loss and fragmentation in western Amazonia as
483 revealed by RAPELD biodiversity surveys. *Acta Amazonica* 51:234-43. <https://doi.org/10.1590/1809-4392202004532>

485 Mozaffari O, Kamali K, Fahimi H (2016) *The Atlas of Reptiles of Iran*. Academic Center for Education, Culture
486 and Research Kharazmi branch Press. Tehran. 361 pp (In Persian).

487 Naderi-Mahdei K, Bahrami A (2014) Ecological potential assessment of soil in agricultural lands in Hamedan
488 Province Iran using geographic information system. *JAEHR* 2: 223-233.
489 <https://doi.org/10.1001.1.26763478.2014.2.4.4.7>

490 Nematollahi S, Fakheran S, Kienast F, Jafari A (2020) Application of InVEST habitat quality module in
491 spatially vulnerability assessment of natural habitats (Case Study: Chaharmahal and Bakhtiari Province,
492 Iran). *Environ. Monit. Assess* 192:1-17. <https://link.springer.com/article/10.1007/s10661-020-08460-6>

493 Nematollahi S, Fakheran S, Jafari A, Pourmanafi S, Kienast F (2022) Applying a systematic conservation
494 planning tool and ecological risk index for spatial prioritization and optimization of protected area
495 networks in Iran. *J. Nat. Conserv* 66:126144. <https://doi.org/10.1016/j.jnc.2022.126144>

496 Norton BA, Evans KL, Warren PH (2016) Urban Biodiversity and Landscape Ecology: Patterns, Processes, and
497 Planning. *Curr. Landsc. Ecol. Rep* 1: 178–192. [https://link.springer.com/article/10.1007/s40823-016-0018-](https://link.springer.com/article/10.1007/s40823-016-0018-5)
498 5

499 Pagaldai N, Arizaga J, Jiménez-Franco V M, Zuberogoitia I (2021) Colonization of Urban Habitats: Tawny Owl
500 Abundance Is Conditioned by Urbanization Structure. *Animals* 11: 2954.
501 <https://doi.org/10.3390/ani11102954>

502 Pearce JL, Kirk DA, Lane CP, Mahr MH, Walmsley J, Casey D, Muir JE, Hannon S, Hansen A, Jones K (2008)
503 Prioritizing avian conservation areas for the Yellowstone to Yukon Region of North America. *Biol.*
504 *Conserv* 141: 908–924. <https://doi.org/10.1016/j.biocon.2007.12.033>

505 **Pressey R. L. (1999). Applications of irreplaceability analysis to planning management problems, *Parks* 9: 42-**
506 **51.**

507 Penjor U, Kaszta Ž, Macdonald DW, Cushman S A (2021) Prioritizing areas for conservation outside the
508 existing protected area network in Bhutan: the use of multi-species, multi-scale habitat suitability models.
509 *Landsc. Ecol* 36:1281–1309. <https://doi.org/10.1007/s10980-021-01225-7>

510 Pflüger FJ, Balkenhol N (2014) A plea for simultaneously considering matrix quality and local environmental
511 conditions when analyzing landscape impacts on effective dispersal. *Mol. Ecol* 23:2146–2156.
512 <https://doi.org/10.1111/mec.12712>

513 Possingham H P, Ball IR, Andelman S (2000) Mathematical Methods for Identifying Representative Reserve
514 Networks. In S Ferson, M Burgman (Eds.), *Quantitative methods for Conservation biology*, New York:
515 Springer-Verlag, 291-305.

516 Reis ARN, Biondi D, Viezzer J, Oliveira JD, Kovalsyki B (2021) Using landscape metrics and species potential
517 distribution modeling in cities to develop the Selection of Areas for Species Conservation Index (SASCI).
518 *Trees* 35: 1341–1350. <https://link.springer.com/article/10.1007/s00468-021-02121-y>

519 Rodrigues A, Akçakaya H, Andelman S, Bakarr M, Boitani L, Brooks T et al (2004) Global gap analysis:
520 priority regions for expanding the global protected-area network. *Bioscience* 54: 1092-1100.
521 [https://doi.org/10.1641/0006-3568\(2004\)054\[1092:GGAPRF\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2004)054[1092:GGAPRF]2.0.CO;2)

522 Sadegh Oghli R, Jahani A, Alizade Shabani A, Goshtash H (2019) Evaluation of Landscape Structure for
523 Development and Integration of the Protected Areas. *TCP* 11: 57-78 (In Persian).

524 Saura S, Bertzky B, Bastin L, Battistella L, Mandrici A, Dubois G (2018) Protected area connectivity: Shortfalls
525 in global targets and country-level priorities. *Biol. Conserv* 219: 53-67.
526 <https://doi.org/10.1016/j.biocon.2017.12.020>

527 Schindler S, Von Wehrden H, Poirazidis K, Wrba T, Kati V (2013) Multiscale performance of landscape
528 metrics as indicators of species richness of plants, insects and vertebrates. *Ecol. Indic* 31: 41-48.

529 Shadkam E, Safari S, Saberi Abdollahzadeh S (2021) Finally, which meta-heuristic algorithm is the best one?
530 *IJDSRM* 10: 32-50. <https://doi.org/10.1504/IJDSRM.2021.117555>

531 Sharp R, Chaplin-Kramer R, Wood S, Guerry A, Tallis H, Taylor R (2014) *InVEST User's Guide: Integrated*
532 *Valuation of Environmental Services and Tradeoffs*. Stanford, CA: The Natural Capital Project. p 321.

533 Shams esfandabad B, Kaboli M (2018) Development of the conservation area network using systematic
534 conservation planning approach in Iran. *J. Anim. Environ* 10:147-162 (In Persian).

535 Shayesteh K, Mohammadyary F (2018) Evaluation and Prediction of Changes in Vegetation Using Landscape
536 Metrics and Markov Model (Case Study: Hamadan). *geogr. dev* 16: 85-104 (In Persian).

537 Smith R J, Cartwright S J, Fairbairn AC, Lewis DC, Gibbon G E et al (2022) Developing a nature recovery
538 network using systematic conservation planning. *Conserv. sci. pract* 4: e578. DOI: 10.1111/csp2.578.

539 Soltani-zoghi A, Serajaddin A, Fatahi Ardakani A (2020) Assessment and Prioritization of Protected Areas
540 Management Strategies in Hamadan Province. *J Environ Sci* 45: 625-643.
541 <http://dx.doi.org/10.22059/JES.2020.288646.1007919>

542 Song W, Kim E (2016) Landscape factors affecting the distribution of the great tit in fragmented urban forests of
543 Seoul, South Korea. *Landscape Ecol. Eng* 12: 73-83. <https://doi.org/10.1007/s11355-015-0280-4>.

544 Spiesman BJ, Stapper AP, Inouye B D (2018) Patch size, isolation, and matrix effects on biodiversity and
545 ecosystem functioning in a landscape microcosm. *Ecosphere* 9: e02173. <https://doi.org/10.1002/ecs2.2173>

546 Topal S, Ongen A (2006) Integrate Protected Areas into Broader land, Seascapes and Sectors from a Social
547 Responsibility of the 292 Environment perspective. *Soc. Responsib. J* 2: 291-299.
548 <https://doi.org/10.1108/17471117200600006>.

549 Walz U (2011) Landscape Structure, Landscape Metrics, and Biodiversity. *LRLR* 5: 1-35.
550 <http://dx.doi.org/10.12942/lrlr-2011-3>

551 Wintle BA, Kujala H, Whitehead A, Cameron A, Veloz S, Kukkala A, Moilanen A, Gordon A, Lentini PE,
552 Cadenhead NCR, Bekessy SA (2019) Global synthesis of conservation studies reveals the importance of
553 small habitat patches for biodiversity. *PNAS* 116: 909-914. <https://doi.org/10.1073/pnas.1813051115>

554 Yousef Siahkalroodi S, Saeedi H, Sadat Behfar M, Fallahi R, Izadian M (2013) *Atlas of Amphibians of Iran,*
555 *publication of Department of Environment of Iran, Tehran, Iran, 110 pp (In Persian).*
556