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Geospatial modeling to identify the effects of anthropogenic processes on landscape pattern change and biodiversity

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Abstract This research used geospatial data to quantify bio-diversity changes and landscape pattern change to track an-thropogenic impacts of such changes at the Mouteh Wildlife Refuge (MWR), Isfahan, Iran. Satellite image duration of four decades, LandSat$_{1-5}$, and IRS-P6 data were used to develop land cover classification maps for 1971, 1987, 1998, and 2011. The number and size of land cover patches, the degree of naturalness, and the diversity indices were calculated and compared for a 40-year period. The results showed an increas-ing concern with regard to unplanned human activities. Some improvements of the natural landscape also occurred in the core protected zone of the study area. The number and size of land cover patches, the degree of naturalness, and the diversity indices were calculated. Overall changes in natural land use between 1971 and 1998 at MWR showed that the number of patches for natural land use has increased, but it also showed a decrease in 2011. Similar changes were observed for semin-atural land use. Within the artificial classes, the number and area of patches were higher and the largest patch occurred in 2011. The maximum variation of diversity is related to the year 2011. The results showed an increasing concern with regard to unplanned human activities. Some improvements of the natural landscape also occurred in the core protected zone of the study area. Remote sensing and geographic information system offers an important means of detecting and analyzing temporal changes occurring in our landscape.

Keywords Landscape ecology · Naturalness · Diversity · GIS · Mouteh Wildlife Refuge

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Introduction

In the last decades, landscape indices have been widely used in assisting decision makers in managing natural resources and valuable habitats of endangered species. The need for those landscapes' ecological tools is becoming more and more essential due to the significant human pressure and impacts that may extend in the future (Wu 2013).

Landscape pattern and its changes in time and location is the result of complex interactions of physical, biological, and social forces (Turner and Ruscher 1988; Turner 2005). Re-cently, human activities have created a decline in biodiversity and related ecosystem services (Rindfuss et al. 2004; Foley et al. 2005; Satake and Iwasa 2006; Quétier et al. 2007; Mitsuda and Ito 2011; Nagendra et al. 2013), and this change is the main agent in shaping many landscapes and their changing patterns. A mosaic of natural landscapes with hu-man blemishes of various sizes and shapes have persisted (Turner et al. 2001; Herzog et al. 2001). Furthermore, newly introduced and changed landscape patterns can affect many of the ecological functions and processes such as energy flow,

animal movement, water drainage, and erosion (Lausch and Herzog 2002). Furthermore, by accurately comparing landscape changes over time, we can understand landscape structure and patterns (de la Fuente de Val et al. 2006). Investigating landscape changes of location and time simultaneously would give decision makers a better appreciation of the their value and how to better manage them (de Barros Ferraz et al. 2005).

The detection of structure and patterns and the investigation of landscape changes specially in larger scales are challenging tasks; many researchers have adapted geographic information system (GIS) techniques and satellite data in landscape studies in order to overcome such hurdle (Herzog et al. 2001; Lausch and Herzog 2002; Apan et al. 2002; Franklin et al. 2002; Bender et al. 2005). Turner et al. (2001) and Farina (2007) noted the exceptional value of satellite data and GIS in analyzing landscapes. Satellite images provide the base information for landscape ecological studies due to their digital format, relative ease of acquisition for location and time, appropriate cover extents, and availability in different spatial, spectral, and radiometric resolutions. Furthermore, GIS, on the other hand, has the potential to analyze landscape elements and to perform sophisticated modeling for landscape ecological change detection and evaluation (Zheng et al. 1997; Turner and Ruscher 1988; Bishop 2003; Salem 2003; Foody 2008). In addition, many landscape ecological studies investigated scale. Turner and Ruscher (1988) observed the effects of changing the grain (the first possible level of spatial resolution with a given dataset) and extent (the total area under investigation) of raster data on calculated spatial pattern indices in order to identify some general rules for comparing measures obtained at different scales. Landscape patterns were compared using indices measuring diversity (H), dominance (D), and contagion (C). The results showed that the diversity index decreased linearly with increasing grain size, but dominance and contagion did not show any linear relationship. On the other hand, many change detection investigations tended to focus on a general description of the land use and many present satellite data as a tool for studying specific ecosystems (Sader et al. 1990; Carlson and Sanchez-Azofeifa 1999; Crossman et al. 2013). Franklin et al. (2002) suggested that in addition to studying the composition of land use types, the study of their spatial distribution and arrangement is also needed to be considered for monitoring changes. Herzog et al. (2001) and Lausch and Herzog (2002) proposed the use of landscape metrics that address landscape patterns and are based on analyzing the geometry and spatial arrangement of land use/land cover patches. In this regard, many landscape ecological indices are used in the investigation and quantification of landscape structure (Urban 2006). O'Neill et al. (1988) used dominance, continuous, and fractal, in order to quantify landscape structure. Turner (2005) used various indices in the field of landscape ecology including diversity,

dominance, number of patches, and maximum and minimum size of patches in different landscape studies. Ayad (2005) used the degree of naturalness, diversity, and topographic changes in investigating the magnitude of landscape changes in the northwestern coastal region of Egypt. Choosing each of these indices for investigation and description of the landscape depends on the scale and purpose of the study (O'Neill et al. 1988; Turner 2005). For example, some indices, such as fractals, are sensitive to human use (Ayad 2005) and others, such as diversity and degree of naturalness, could describe landscape esthetic values (Turner et al. 2001; Ayad 2005). Furthermore, landscape ecological diversity indices have a key role in the stability of habitats and communities. Shannon-Weaver diversity index is widely used as a major indicator for measuring habitat diversity in landscape ecological analysis (O'Neill et al. 1988; Ayad 2005). The advantage of Shannon diversity index lies in its sensitivity to rare land use/cover classes, which would be suitable for application in arid and semiarid landscapes where land cover is usually widely dispersed (Romshoo and Rashid 2014). The resulting values of this index incorporate the amount of information per individual land use/cover class (Ayad 2005).

The objective of the present study was to investigate four decades of changes in Mouteh Wildlife Refuge from a landscape ecology perspective. Due to the extents and the type of landscape features of Mouteh Wildlife Refuge and due to the purpose of the study, which concentrates more on the support of conservation and protection of the natural resources of the study area, the mean number and size of patches, landscape diversity (Shannon diversity index), and degree of naturalness were selected in order to assist in quantifying the landscape structure and to identify its patterns.

The study area

The Mouteh Wildlife Refuge has a diverse natural composition and is rich in plant and animal species. It is located in Isfahan Province, Iran, with an area of around 204,000 ha. It is located between longitudes 50° 13′ and 51° 02′E and between latitudes 33° 23′ and 34° 01′N (Fig. 1). The elevation of the study area varies between 1,900 and 3,000 m. The area has two main climatic regions: First is the flat salt lands of Mouteh and the second is the north mountains of Mouteh and the regions around Gol Cheshmeh which has a mountainous climate. The dominant species in the plains are *Artemisia* and *Anabasis*; foothills and highlands, *Acantholimon*; watercourse, *Pteropyrum*; rockyland, *Amygdalus*; and degraded areas, *Carex*, *Noaea*, *Euphorbia*, and *Scariola*. The dominant species is *Astragalus* sp. and *Artemisia sieberi* in the plains and *Artemisia aucheri* in the highlands. In general, the study area's climate, according to Domarton's approach, is semiarid. Its annual precipitation is around 250–300 mm. The
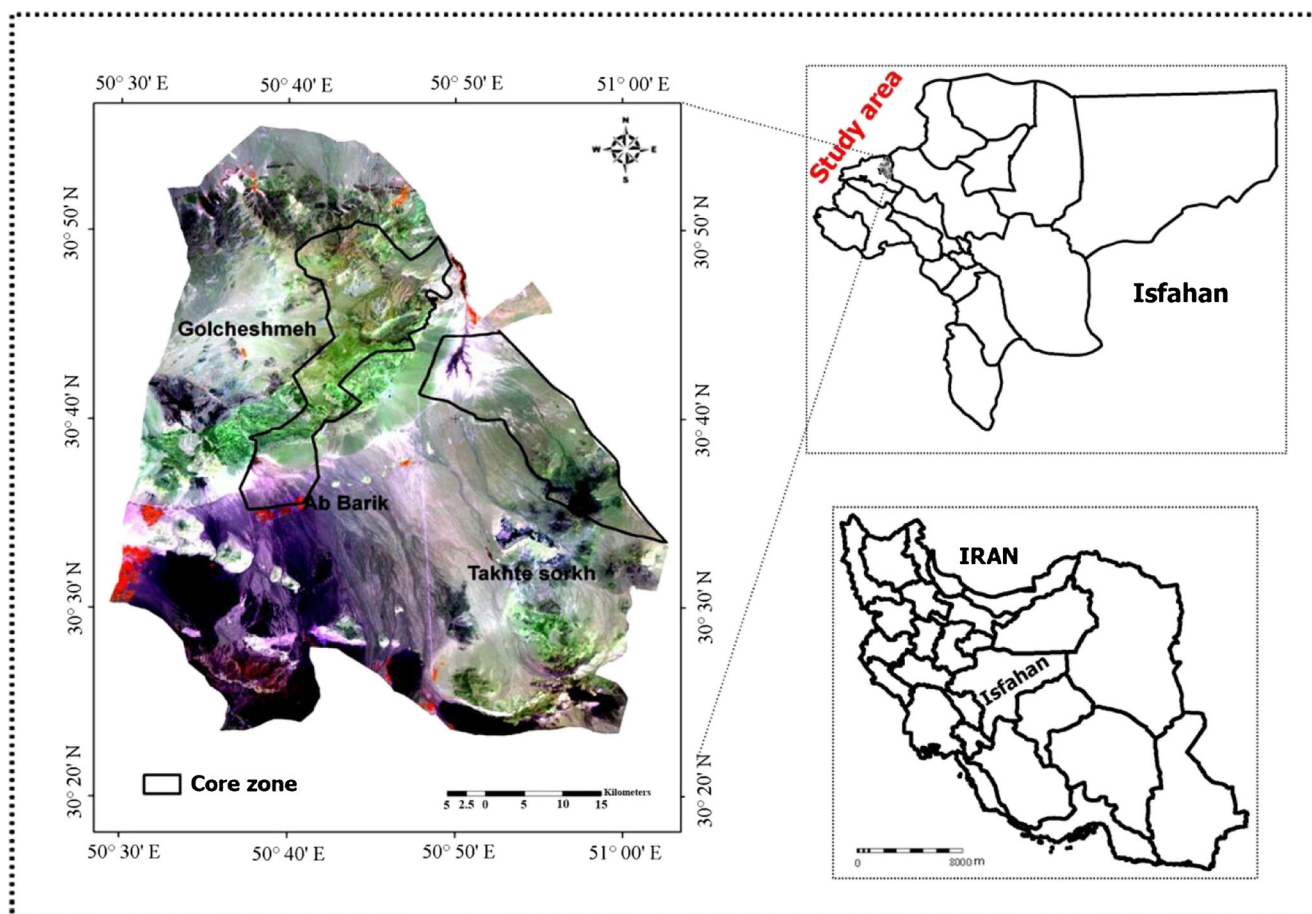
Fig. 1 The location of the main study area

maximum amount of rainfall usually occurs in December and January (approximately 26 mm). The temperature varies between −27 and +38 °C which occurs in January and August, respectively. This refuge has a unique collection of plant and wildlife specially of large mammals. During the past four decades, many refuge natural habitats were destroyed. This was mainly due to mining activities and overgrazing, which had a great impact on its landscape.

Materials and methods

Satellite datasets

Satellite image data for this research is collected through a remote sensing agency. Four almost cloud-free satellite images of LandSat$_{1-5}$ and IRS-P6 LISS-III were selected in order to cover a period of significant change in the study area's landscape. Close attention was given to select an interval that would represent different socioeconomic and spatial changes in order to measure its impacts on the current landscape structure. A list of the adopted data is given in Table 1.

Data and methodology

All images were resampled to 30-m resolution using IDRISI Selva in order to ensure the integrity of further spatial comparisons between different sensors. Satellite images were georeferenced using the topographic maps and GPS collected ground control points, in order to ensure the best alignment between the different dates (Usery et al. 2004). The following previous conservation schemes and field observations were divided into 11 classes (Table 2). Due to the complexity of object reflectance in the study area, the satellite images were classified using different methods. Soil-adjusted vegetation

Table 1 Digital topographic map and satellite image data

Data	Date	Resolution
Topographic map	–	1/25,000
LandSat$_1$ MSS	17 June 1971	60 m
LandSat$_5$ TM	5 June 1987	30 m
LandSat$_5$ TM	3 June 1998	30 m
IRS-P6 LISS-III	7 June 2011	23.5 m

Table 2 General land use/cover classes and description

Code	Land use/cover	Description
1	Cover 0–10 %	Area with lower 10 % vegetation crown cover
2	Cover 10–20 %	Area with between 10 and 20 % vegetation crown cover
3	Cover 20–40 %	Area with between 20 and 40 % vegetation crown cover
4	Cover > 40 %	Area with upper 40 % vegetation crown cover
5	Salt land	Lowland with near surface groundwater
6	Farmland	Areas currently under crop cultivation, orchards, and/or fallow land
7	Tamarisk and junk	An area that is covered with tamarisk and junk usually located nearby salty land and shallow surface water
8	Schist	Black rocky area
9	Mine	It involves all mining activities in past and present
10	Rock	An area that is rocky and shelved. This area is usually a suitable habitat for ibex
11	Settlement	An area where permanent inhabitants are located. Man-made structures dominate

index (SAVI) was used for producing the vegetation maps. SAVI was developed to reduce or eliminate the soil influence on solar reflectance values (Huete 1988; Qi et al. 1994). The SAVI index is a superior vegetation index for low-coverage environments (Gilabert et al. 2002). SAVI was calculated using Eq. (1):

$$SAVI = \left(\frac{(NIR-R)}{(NIR + RED + L)} \right) \times (1 + L) \qquad (1)$$

where L is a constant that is empirically determined to minimize the vegetation index sensitive to soil background reflectance variation. If L is zero, SAVI is the same as NDVI. For intermediate vegetation cover ranges, L is typically around 0.5 (Zhang et al. 2009).

The correlation equation between SAVI vegetation index as an independent variable and vegetation cover as a dependent variable was calculated. The result was divided into four classes: vegetation covers of less than 10, 10–0, 20–40, and higher than 40 %. Second, the stone and rock classes were extracted using the separated first component of a principal component analysis (PCA). Finally, all other land cover classes, including salt lands, orchard and farmland, schist, mine, fallow land, and settlement areas, were obtained using a supervised classification. Finally, all of those three classification layers were combined together in order to provide the final land use/cover map of the study area.

Transition matrices of the land use/cover using spatial change detector

Using the SCD software extension, the activity layers were combined and the degree of naturalness classes was implemented on the multi-temporal maps (Amiri et al. 2013).

Accuracy assessment

To assess the accuracy of the produced maps, random points were checked against field ground control points and the topographic map of date 2002 for 2011, and the false color composites (FCC) and the available topographic maps of date 1990 for 1998. The visual interpretation of FCC and information collected from the local people were used to assess the 1971 and 1987 classified images. The accuracy of the produced maps for 1971, 1987, 1998, and 2011 was 85, 92, 89, and 92 %, respectively.

Quantify landscape features

In support of evaluating the area under consideration for conservation goals and for land use/cover evaluation, the number of patches and the smallest and the largest patch were calculated using two indices: the degree of naturalness of land use/cover activity and the proportional distribution of land use/land cover diversity. Figures 2 and 3 summarize the research methods are presented.

In order to measure the degree of naturalness, the number of patches was determined and the largest and smallest patch sizes were identified, and the land use/cover maps were reclassified into natural, seminatural, and artificial land uses based on usage type (Table 3). The degree of naturalness maps was calculated using Eq. (2) in an aggregated block of 7×7 cells for each date:

$$PP_i = INT\frac{100}{x}\sum N_i \qquad (2)$$

where PP_i is the percentage of the proportional distribution of activity i, INT is a function that transforms the result into integer values, x is the total number of cells in each block, and N_i is the activity of identification i (Ayad 2005).

This resulted in three separate layers, one for each of the degree of naturalness classes for each date. These were then combined and reclassified. The final degree of naturalness map for each date resulted in six classes. Table 4 shows the resulting degree of naturalness classes.

The Shannon diversity index (SHDI) (Shannon and Weaver 1949) was calculated in order to investigate the landscape diversity for the same 7-m×7-m block for each year according to the following equation:

Fig. 2 Method to extract the degree of naturalness from land use/cover maps
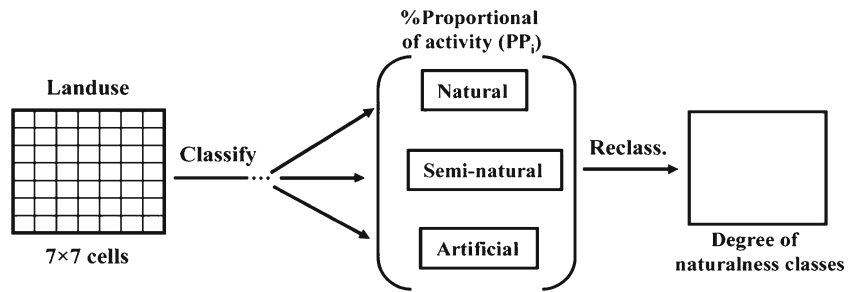
$$SHDI = -\sum P_i \ln P_i \qquad (3)$$

where SHDI is the Shannon diversity index, i is the class, and P_i is the proportional distribution of a class i in a specific study area. The value of P_i always varies between 0 and 1; therefore, the logarithm of P_i will always be a negative value (except for 0 which will give infinity and for 1 which will give 0). P_i is calculated as $P_i = n_i/N$, where N is the total area of each block and n_i is the area occupied by each land use/cover in the same block.

The resulting maps were then reclassified to four diversity classes. Table 5 shows the resulting diversity map classes and their corresponding SHDI value ranges. The calculation of the degree of naturalness and the diversity indices was carried out for all available 4 years land cover data. They were compared using an overlay method.

Results

Number of patches, area of patches, and patch sizes

Table 6 shows the resulting number of patches, areas, and maximum and minimum size of patches in all 4 years. The results show that the number of patches for natural land use has increased from 1971 to 1998, but it also shows a decrease in 2011 by almost 50 %. The year 1998 had the most number of natural patches. The maximum patch size in this class had not significantly changed. Changes of seminatural land use followed the same trend, but, on the other hand, the number of patches in this class was more than the natural patches during

the study period. Within the artificial classes, alternatively, the number and area of patches were higher and the largest patch occurred in 2011. The number of patches in 2011 was ten times higher than in 1971, and the patch sizes were five times larger as well.

Naturalness

Figure 4a–d shows the degree of naturalness calculated for all study dates. By comparing the total areas of each degree of naturalness class between 1971 and 2011, it becomes clear that most changes occurred in the natural class (class 1), which witnessed a 30 % decrease during this period, an approximate 0.85 % change per year. Furthermore, the overlay result shows that a significant conversion of natural lands occurred, 11.73 % of which were transformed into seminatural and 19 % into natural/seminatural during the period between 1971 and 2011, these areas are always near the roads and usually fall outside the core zone. Also between 1971 and 1987, most of the converted classes (45 %) were natural which were converted to natural/seminatural. Table 7 shows the major conversions in the degree of naturalness between the years presented within the study period. Between 1987 and 1998, on the other hand, approximately 23 % of natural/seminatural lands were converted to seminatural. This indicates a step transition of the natural lands from natural/seminatural to seminatural. But between 1998 and 2011, most of the converted classes are natural/seminatural which changed to natural land. The maps in Fig. 4 show that these areas fall mostly in the core zone, which indicates a progress in the conditions of these areas.

Figure 5 shows the trend of change of the degree of naturalness classes in the study area. The negative slope in

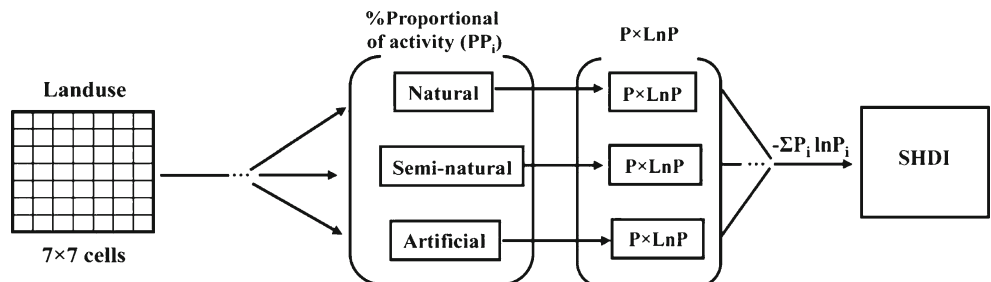**Fig. 3** Method to extract the land use/land cover diversity classes

Table 3 The selected activity group of classes

Code	Activity	Land use/cover
1	Natural	Cover 0–10 %
		Cover 10–20 %
		Cover 20–40 %
		Cover 40 %<
		Salt land
		Rock
		Tamarisk and junk
2	Seminatural	Schist
		Farmland
3	Artificial	Mine
		Settlement

Fig. 5a clearly shows the areas of natural lands decreasing by 46.34 % during the period between 1971 and 1987 (Table 8), but this trend changed after 1987 since it increased by 9.5 % during the period between 1987 and 1998 and by 7.7 % during the period between 1998 and 2011. Furthermore, Fig. 5b shows the increase in the seminatural lands from 1971 to 1998 while it had no significant change from 1998 to 2011. Table 8 shows a 3 % minor increase of the seminatural areas in 1987 and a major increase of 22.5 % in 1998. The natural/seminatural areas, on the other hand, have increased (Fig. 5c); they occupied 63 % of the study area.

Finally, Fig. 5d and Table 8 show the increasing trend of the areas of human activities during the study period. The rate of change in the artificial land (class 3) is the highest of all at more than 750 % between 1971 and 1987, it slowed down between 1987 and 1998 (58 %), and then it continued to be the highest again between 1998 and 2011 with more than 153 % increase. Also, Table 8 shows that in 2011, 16.3 ha of the land was occupied by a mix of natural and artificial covers and

Table 4 The suggested combination of the degree of naturalness classes

ID	Description	Composition (%)
1	Only natural classes	1>68
12	Combination between natural and seminatural classes	3>16
		16<1<68
		16<2<68
2	Only seminatural classes	2<68
23	Combination between seminatural and artificial classes	1<16
		16<2<68
		16<3<68
3	Only artificial classes	3<68
13	Combination between artificial and natural classes	2<16
		16<1<68
		16<3<68

Table 5 Different diversity classes extracted from the study area (Ayad 2005)

ID	Description	SHDI
1	No diversity	0
2	Low diversity	0<SHDI<0.5
3	Intermediate diversity	0.5≤SHDI<1
4	High diversity	SHDI=1

12.01 ha was mainly covered by a mix of seminatural and artificial classes. Most of the study area (72 %) was covered by natural lands (class 1) in 1971 and subsequently was changed to a mix between natural and seminatural (class 12) in 1987. The natural/seminatural areas represented 21 % of the total area in 1971 and increased to 64 % in 1987. Moreover, natural areas decreased to 26 % of the total area in 1987. The decreasing area of natural lands and the increase in the seminatural and artificial classes specially in the period between 1971 and 1987 indicate the rapid conversion of the natural areas into more man-made landscapes.

Diversity

The north and the southwest regions of the study area witnessed the most change in diversity (Fig. 6). In the north, areas with high diversity were notably reduced in favor of low and intermediate diversities during the period between 1971 and 1987. It gradually converted back to the high diversity class afterwards. Furthermore, the southwestern region of the study area witnessed a gradual substitution to a nondiverse landscape throughout the study period.

In general, the areas with no diversity increased by 700 % and the areas of high diversity, on the other hand, have increased by 35.3 % during the study period (Table 9). The extent of change of the areas of no diversity which significantly increased from 1971 to 1998 then shows a slight decrease in the area between 1998 and 2011. Figure 7b, on the other hand, shows the changes in the areas of low diversity. An increasing trend in this class is depicted between 1971 and 1987, and then, a relatively continuous decrease is shown until 2011. Furthermore, the areas of intermediate diversity have witnessed a slight overall decrease during the study period. It was somewhat consistent from 1971 to 1987, but then, it showed a more rapid decreasing trend between 1998 and 2011. Finally, although the areas of high diversity showed an increase during the first period (between 1971 and 1987), it started a gradual increase from 1987 until 2011.

A general trend within the study period (1971–2011), as shown in the transition matrices in Table 10, indicates mostly a conversion of the intermediate diversity classes to higher diversity (16.82 %). On the other hand, between 1971 and 1987, 12 % of the high diversity class has mostly changed to

Table 6 Number of patch, area of patches, and maximum and minimum size of patch

Year	Land use											
	Natural				Seminatural				Artificial			
	Min	# of patches	Max	Total area	Min	# of patches	Max	Total area	Min	# of patches	Max	Total area
1971	0.01	6,047	19,630	197,210.2	0.01	6,337	2,926.5	7,020	0.01	93	38.6	176.6
1987	0.01	6,051	19,471.5	195,509.8	0.01	6,003	1,587.8	8,519.7	0.01	320	60.3	420
1998	0.01	6,728	19,444.3	195,252.6	0.01	6,330	1,592.1	8,408.3	0.01	847	85.1	763.4
2011	0.01	3,652	19,318	194,214.3	0.01	3,572	2,922.2	9,058.2	0.01	910	197	1,035.2

intermediate diversity while some of the intermediate diversity has changed to low diversity (11.63 %). During the period between 1987 and 1998, the highest conversion was from the intermediate to high diversity (15 %). Furthermore, this trend
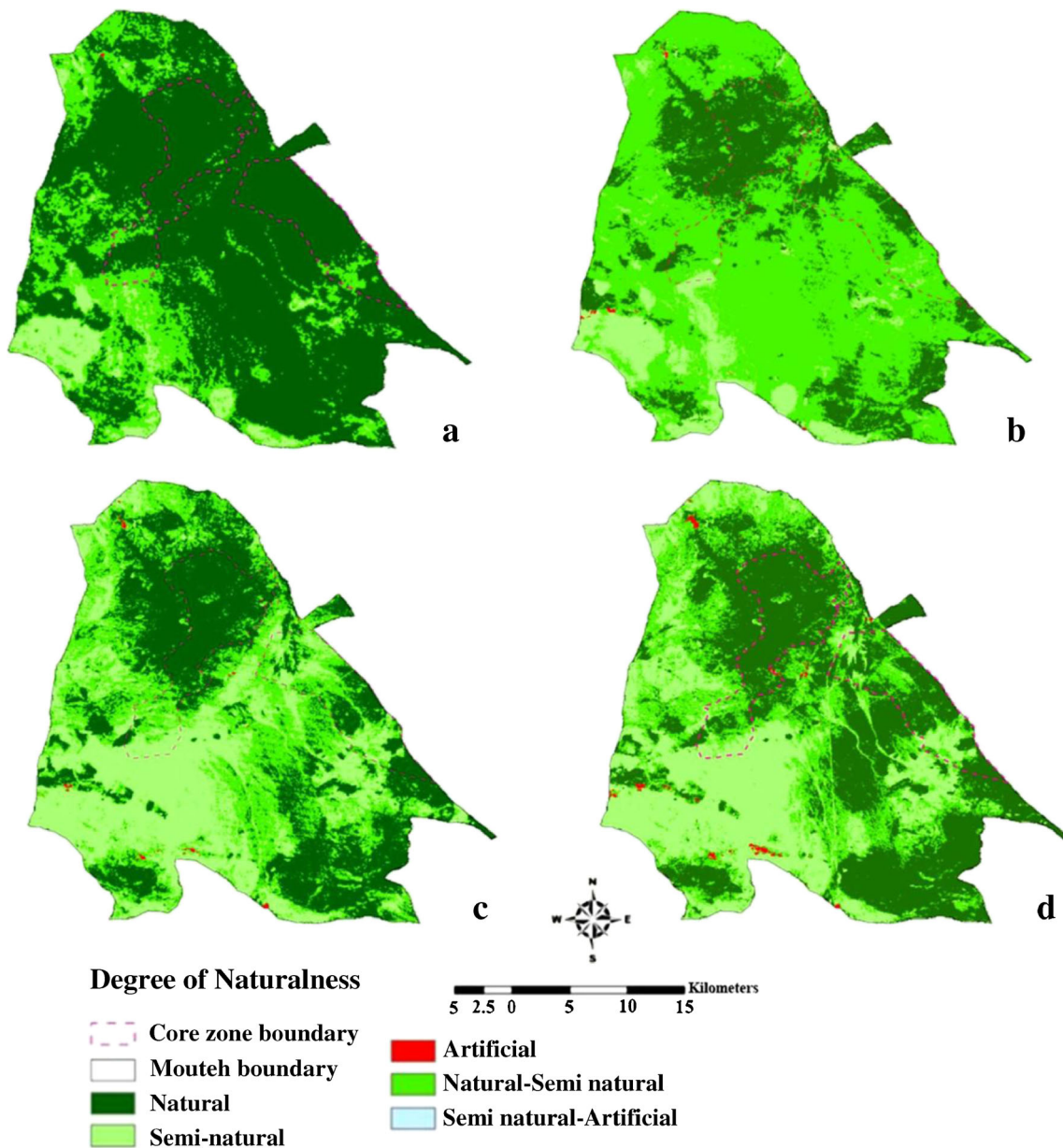

Fig. 4 The degree of naturalness extracted from land use/land during the study period: **a** 1971, **b** 1987, **c** 1998, and **d** 2011

Table 7 Transition matrices of the changes in the naturalness classes between the different dates under investigation

		1987						
		1	2	12	3	13	23	Total
1971	1	53.42	0.72	45.80	0.06	0.00	0.00	100
	2	0.00	98.96	1.04	0.00	0.00	0.00	100
	12	0.00	0.00	100.00	0.00	0.00	0.00	100
	3	0.00	0.00	0.00	100.00	0.00	0.00	100
	13	0.00	0.00	0.00	0.00	100.00	0.00	100
	23	0.00	0.00	0.00	0.00	0.00	100.00	100
		1998						
		1	2	12	3	13	23	Total
1987	1	95.80	0.90	3.30	0.00	0.00	0.00	100
	2	0.09	98.71	1.20	0.00	0.00	0.00	100
	12	13.00	23.00	63.95	0.05	0.00	0.00	100
	3	0.00	0.00	0.00	100.00	0.00	0.00	100
	13	0.00	0.00	0.00	0.00	100.00	0.00	100
	23	0.00	0.00	0.00	0.00	0.00	100.00	100
		2011						
		1	2	12	3	13	23	Total
1998	1	94.60	0.50	4.90	0.00	0.00	0.00	100
	2	2.08	92.12	5.80	0.00	0.00	0.00	100
	12	11.05	6.20	82.58	0.17	0.00	0.00	100
	3	0.00	0.00	0.00	100.00	0.00	0.00	100
	13	0.00	0.00	0.00	0.00	100.00	0.00	100
	23	0.00	0.00	0.00	0.00	0.00	100.00	100
		2011						
		1	2	12	3	13	23	Total
1971	1	68.97	11.72	19.08	0.23	0.00	0.00	100
	2	0.00	99.72	0.28	0.00	0.00	0.00	100
	12	0.00	0.00	100.00	0.00	0.00	0.00	100
	3	0.00	0.00	0.00	100.00	0.00	0.00	100
	13	0.00	0.00	0.00	0.00	100.00	0.00	100
	23	0.00	0.00	0.00	0.00	0.00	100.00	100

1 natural, *2* seminatural, *3* artificial, *12* combination between natural and seminatural classes, *13* combination between artificial and natural classes, *23* combination between seminatural and artificial classes

continued during the period between 1998 and 2011 where the same conversion repeated with a relatively high rate (12 %).

Discussion

The increasing trend of the number of patches, in general, indicates higher landscape fragmentation (O'Neill et al. 1988; Turner and Ruscher 1988). The results showed an increasing number of patches and size of maximum patch of natural land use between 1987 and 1998 which indicates a higher fragmentation process during this period, and a relative decrease in 2011 denoting a gradual recovery of the natural landscape. Furthermore, the areas of the natural landscape have decreased to 46.34 % of the total area in 1987 and they increased by 9.5 % from 1987 to 1998 and by 7.7 % from 1998 to 2011. This indicates that the number of patches and their sizes are significantly related to indicate a recovery process that occurred in the study area during the last periods under investigation. Almost the same trend occurred in the seminatural areas; it showed an increase until 1998 (3 % from 1971 to 1987 and 22.5 % from 1987 to 1998) with an insignificant change between 1998 and 2011, while the number of patches decreased. This also suggests a relatively healthy landscape ecological process in this class.

Furthermore, the conversion process between the degree of naturalness classes is specially noticeable in the natural/seminatural areas where it increased in 1987 in favor of the seminatural areas (63 % of the total area), while it decreased in the following years in favor of the natural and seminatural

Fig. 5 Changes of the different degrees of naturalness classes (in land use/cover) between 1971 and 2011: **a** natural, **b** seminatural, **c** artificial, and **d** natural/seminatural
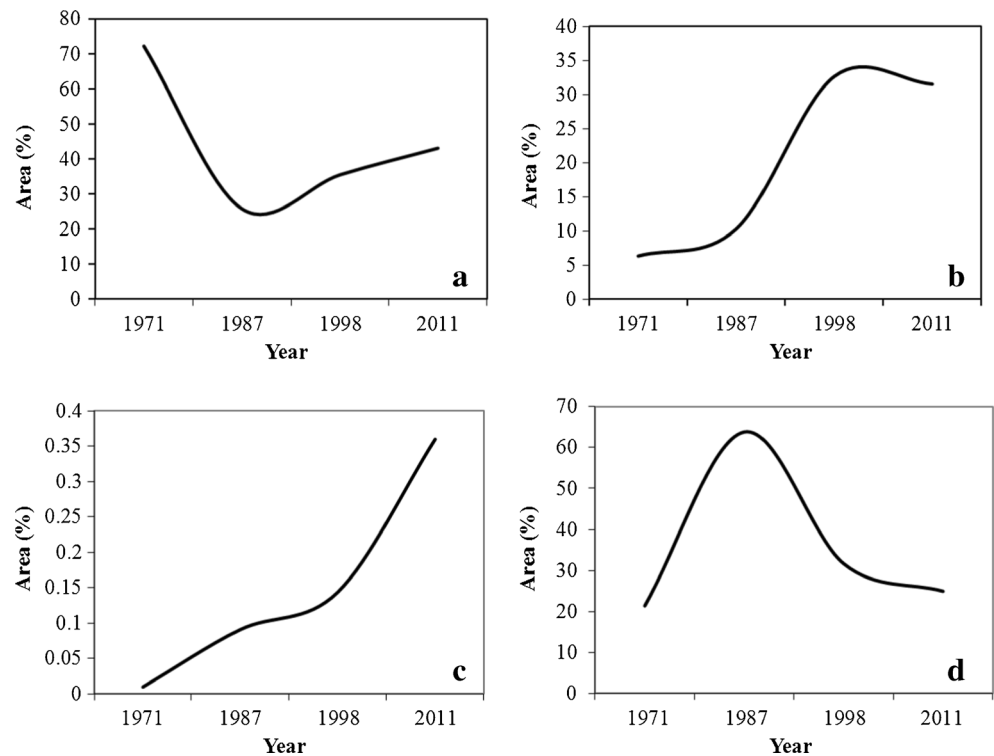
classes. By investigating the resulting maps more accurately, it can be noticed that the areas converted to the natural classes are those considered as a protected core zone for the refuge, those areas expanded by 17.3 % in 2011 from 1987. This mainly occurred due to management efforts in controlling the human impacts by reducing the overgrazing activities. But, on the other hand, some areas including farmlands around the Ab Barik precinct were converted from natural/seminatural class to seminatural class due to the lack of sound landscape management of the uncontrollable human use that increased during this period.

Although the increasing number of patches is one of the major landscape fragmentation factors (O'Neill et al. 1988; Turner and Ruscher 1988). But for the non-natural areas (man-

made landscape), it would show the development of that particular land use and it could be an alarming indicator of the conversion of natural to a more synthetic, man-made landscape. The current results depict an increase in human activity patches' quantities, areas, and maximum size between 1971 and 1986. However, the development of human activities is more noticeable during the period between 1998 and 2011. Although this change is less than the other classes in the whole study area, but the rate of change is alarming: more than 750 % increase in total artificial areas between 1971 and 1987, 56 % between 1987 and 1998, and more than 150 % between 1998 and 2011 (Table 8). And, even though the introduction of some activities, such as mining and industrialization, is minimal as compared to the total area of the other land

Table 8 Changes in the degree of naturalness between 1971 and 2011

| Class	1971			1987			1998			2011	
	Area (ha)	From total %	71–87 change %	Area (ha)	From total %	87–98 change %	Area (ha)	From total %	98–11 change %	Area (ha)	From total %
1	147,408.40	72.26	−64.11	52,610.48	25.90	36.83	72,396.30	35.49	21.50	87,960.44	43.12
2	12,980.30	6.36	62.08	21,038.40	10.30	217.12	66,716.90	32.70	−3.48	64,392.47	31.56
3	21.87	0.01	757.84	187.61	0.09	56.18	293.00	0.14	153.98	744.17	0.36
12	43,597.60	21.37	198.58	130,171.80	63.71	−50.39	64,579.67	31.66	−21.21	50,883.17	24.94
13	0.00	0.00	–	0.00	0.00	–	0.00	0.00	–	16.30	0.01
23	0.00	0.00	–	0.00	0.00	–	22.42	0.01	−46.43	12.01	0.01
Total	204,008.17	100.00	954.39	204,008.29	100.00	2.60	204,008.29	100.00	1.04	204,008.56	100.00
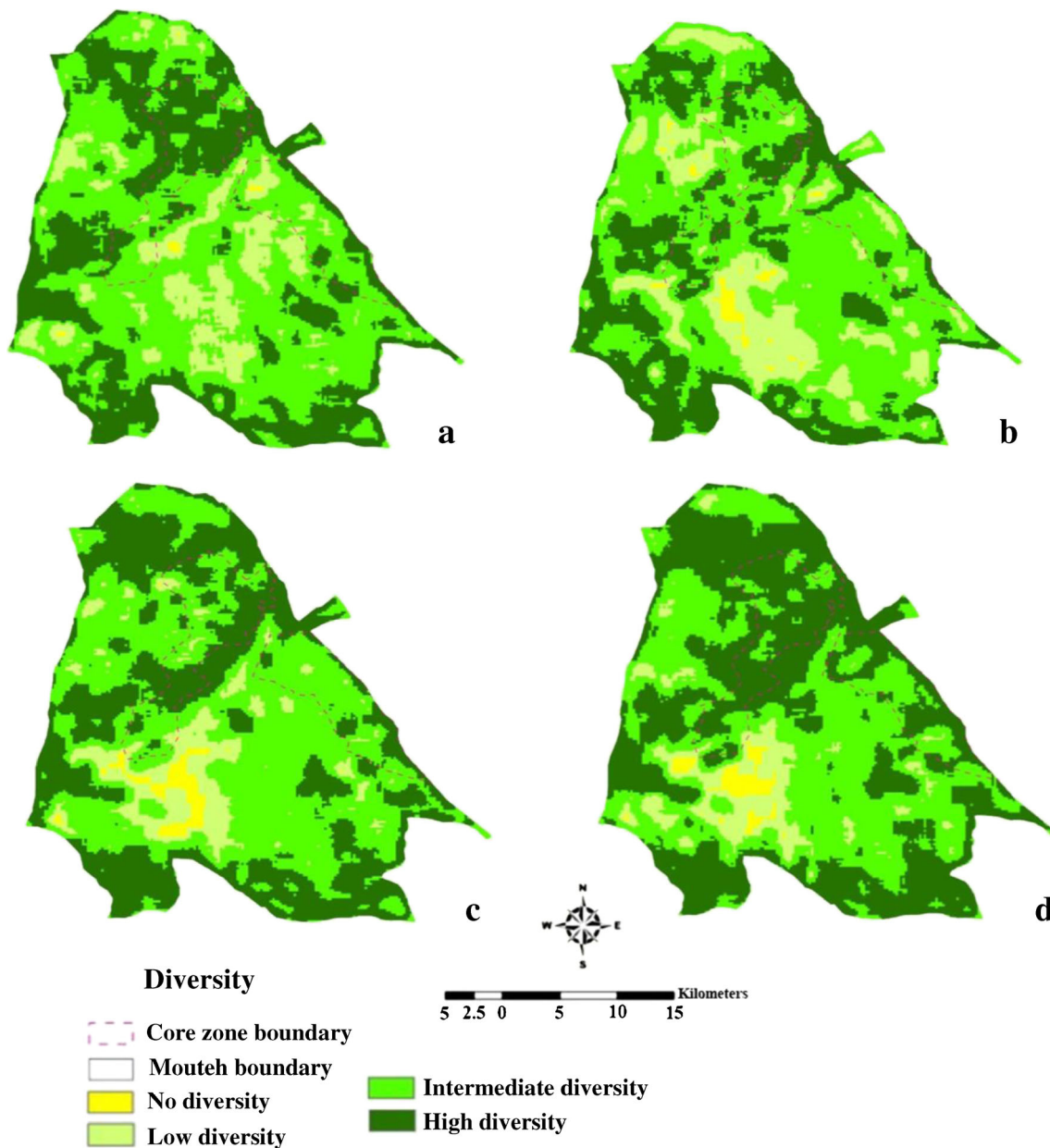
Fig. 6 The extracted land use/land cover diversity classes during the study period: **a** 1971, **b** 1987, **c** 1998, and **d** 2011

cover/use classes during the past four decades (1 % of whole study area), its impact on the study area could exceed just the substitution of land use/cover classes. This could be attributed to air, land, and water pollutions, beside the destruction of the esthetic values of the landscape through mining, development of new residential areas in order to accommodate population growths, and the increasing human pressure which could have irreversible impacts on the landscape.

Furthermore, when comparing the four resulting diversity maps, the areas with no diversity (class 1) and those with high diversity (class 4) showed an increase of 1.5 and 12.24 %, respectively, from 1971 to 2011. By investigating the land use map and the degree of naturalness, it becomes obvious that the

higher diversity areas are part of the 40 % vegetative cover or higher, which denotes an improvement of the landscape's natural habitats. But, in other parts specially in the center of the study area (Fig. 1), areas with higher diversity are related to mining land use (nonnatural). In those areas, the higher the diversity represents the demolition and/or absence of natural habitats. The substitution of the original landscape has caused an increase in the diversity index.

The increase in the no diversity classes during the period between 1971 and 1998, on the other hand, is most noticeable around the area of Ab Barik which include regions where overgrazing took place. The land use map shows that the land cover of those parts (10–20 % vegetative cover) was replaced

Table 9 Changes in the study area diversity between 1971 and 2011

| Class	1971 Area (ha)	From total %	71–87 change %	1987 Area (ha)	From total %	87–98 change %	1998 Area (ha)	From total %	98–11 change %	2011 Area (ha)	From total %	71–11 change %
1	45,644.00	0.22	436.10	2,447.02	1.20	68.11	4,113.80	2.01	−11.55	3,659.08	1.70	701.00
2	26,931.90	13.20	31.23	35,343.58	17.30	−43.57	19,943.70	9.70	−12.28	17,493.54	8.57	−35.00
3	105645.91	51.76	0.00	105649.76	51.76	−4.24	101167.08	49.56	−14.15	86846.46	42.55	−17.00
4	71,059.17	34.81	−14.64	60,653.14	29.71	30.03	78,868.83	38.64	21.84	96,094.41	47.08	35.32
Total	249,280.98	100.00	452.69	204,093.50	100.00	50.33	204,093.41	100.00	−15.64	204093.49	100.00	684.32
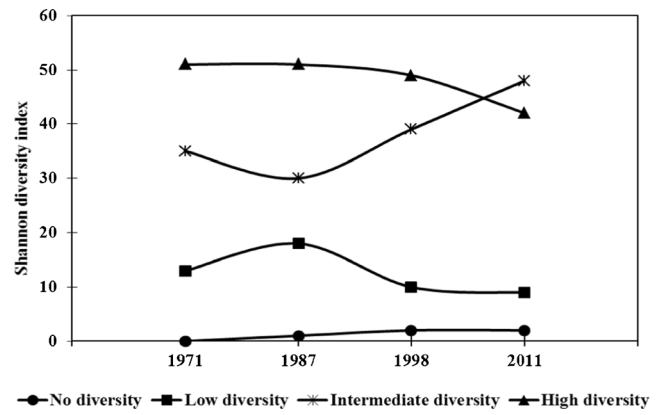
Fig. 7 Change trends of the land use/land cover diversity classes between 1971 and 2011: **a** no diversity, **b** low diversity, **c** intermediate diversity, and **d** high diversity

by the 0-10 % vegetation cover and the absence of land cover class2. The low diversity areas, on the other hand, showed an increase from 1971 to 1987, then; it started to decrease in favor of a more diverse landscape till 2011.

Furthermore, the areas of high diversity showed a decrease from 1971 to 1987 and then increased to 2011. This is not mainly a favorable landscape condition since most of those

Table 10 Transition matrices for the diversity changes between the different dates under investigation

		1987 1	2	3	4	Total
1971	1	99.83	0.04	0.13	0.00	100
	2	0.36	91.68	7.47	0.49	100
	3	0.78	11.63	79.55	8.04	100
	4	0.77	0.00	12.85	86.38	100
		1998 1	2	3	4	Total
1987	1	99.23	0.54	0.23	0.00	100
	2	0.96	87.55	11.06	0.43	100
	3	0.63	4.12	80.25	15.00	100
	4	0.24	0.000	6.27	93.49	100
		2011 1	2	3	4	Total
1998	1	98.91	1.09	0.00	0.00	100
	2	0.90	95.17	3.75	0.18	100
	3	2.52	0.00	85.41	12.07	100
	4	0.00	0.00	3.81	96.19	100
		2011 1	2	3	4	Total
1971	1	99.79	0.05	0.16	0.00	100
	2	0.60	89.13	9.29	0.98	100
	3	1.18	6.11	75.89	16.82	100
	4	0.00	0.09	5.45	94.46	100

1 no diversity, *2* low diversity, *3* intermediate diversity, *4* high diversity

areas are close to the regions of relatively heavy human use. This, as expected, would have a positive effect on the diversity index. By analyzing the land use map for those regions, it becomes apparent that in some areas, including the southeast of the Mouteh Wildlife Refuge north of Takht-e Sorkh Mountains (Fig. 1) and just outside of the core zone, land cover classes 2 and 3 have been demoted to class 1 with a vegetation cover of 0–10 % in the period between 1971 and 1998. A similar change also occurred in the areas west of the core zone of Gol Cheshmeh (outside of the study area) with a vegetation cover of 20–40 % (class 3) which reduced to 10–20 % (class 2). The introduction of new land use classes in the study area has generally contributed to the increase in the diversity index; those classes were mainly mining and other residential and industrial developments. But, on the other hand, because of the improvement of the vegetation cover in the core zone, more favorable, higher diversity could be identified; those are part of those areas that were mainly converted into the natural class (Fig. 4). The extent of this class has increased by 1987. It is therefore prudent to point out that some changes in the diversity index have occurred due to a progress in the landscape recovery process and others due to the destruction and substitution of the natural landscape to a more man-made synthetic environment.

Conclusions

The maximum overall diversity index in 1971 was 0.85. It decreased in 1987 to 0.79 and then continued to increase until 2011. The average diversity on the other hand was 1.9 in 1971, and it then witnessed a subsequent fluctuating trend until 2011. Those results, when compared side by side with the land use/cover and the degree of naturalness maps, show that the increase in the diversity index was mainly due to a general increase in the number of land use classes and that the degree of naturalness is lower in those areas where the diversity index has increased during the previous years. So it can be concluded that although the diversity has increased in some areas, the degree of naturalness has decreased due to the introduction of the artificial land use. Therefore, the general increase in the diversity can be attributed to the development of the artificial land uses. The interpretation of the resulting diversity maps emphasizes that the man-made artificial land uses continue to be developed and that this can be considered as a warning of the continuing loss of the area's natural habitats and its native landscape. Generally, it can be concluded that in the 35 years of the current study's investigation, the study area has been repaired specially in the core zone and, therefore, has improved its natural processes and significantly recovered its indigenous landscape. But in other parts, the destruction process is continuing rapidly. Plans for the protection and management of the development of the areas outside of the core zone should be traced since the unmanaged human activities can have adverse and irreversible effects on the current landscape.

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