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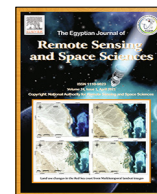
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Research Paper

Assessing and monitoring the effects of land cover changes in biodiversity. Case study: Mediterranean coastal region, Sousse, Tunisia



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ABSTRACT

In the Mediterranean regions, habitat degradation, alteration, and even destruction were major causes of the rarefaction of species in their natural environment. In the last decade, these phenomena are further amplified by the reduction of natural vegetation cover, urban sprawl, and climate change. In addition, the degradation of plant cover through cropping, and intensive agricultural practices causes soil erosion, habitat destruction, and loss of biodiversity. While to reduce these risks, it is necessary to assess and monitor Land Use Land Cover changes that will be crucial information for managing natural resources and guiding decision-making processes in their development plans. This is the case of a Mediterranean coastal region, Sousse, Tunisia which is characterized by its landscape diversity and the richness enhanced by the coastal and marine fauna and flora. The methodology is based on the use of Remote Sensing and Geographical Information System where different tools and functions have been employed such as Maximum Likelihood classification validated with field truth, thematic changes using classification change matrix, etc. The establishment of a multi-scalar landscape approach revealed changes in land use on a regional scale between 2007 and 2017. The landscape of Sousse region has been strongly modified by the action of Man where we note a significant growth of built-up areas and a regression of cultivated areas. From 11.84 % to 14.14 %, and from 28.83 % to 21.70 %; respectively. Hence, the growing risk of fragmentation of natural habitats, forests and agricultural areas. The development plan proposed in favor of biodiversity conservation offers a concrete example and can be useful for developing appropriate land use policy for sustainable region in Tunisia and similar Mediterranean regions. This is an essential study for all land use planning proposals as a guide to landscape conservation, enhancement and protection.

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1. Introduction

Tunisia is characterized by its great diversity of environments and ecosystems such as forests, steppes, oasis, marine, etc. These spaces are home to important biological diversity (Boussema & Allouche, 2020). However, anthropogenic activities of the national territory have helped to modify these ecosystems. Thus, there has

been increasing pressure on the remaining natural ecosystems as a result of overgrazing, the mobilization of water for agriculture, and the over-exploitation of agricultural environments and fisheries resources. The Tunisian agricultural environment is then greatly affected (Negm et al., 2021; Khebour Allouche et al., 2021). This results in a shrinking of the extent of natural ecosystems and an impoverishment of their biodiversity (Radhouane, 2013). Recently, from the report of the National Biodiversity Strategy and Action Plan 2018–2030, the main pressures and threats to biodiversity in Tunisia are: a) climate change; b) unsustainable use and management of natural resources; and (c) habitat degradation, fragmentation, and loss, which affects all ecosystems (PNUD, 2020). According to Sala et al. (2000), land use has been identified as the major driver of global biodiversity change by the year 2100. Moreover, land cover is an essential input for creating a reliable

Abbreviations: ENVI, Enviroment for Visualizing Images; GIS, Geographical Information System; INS, National Institute of Statistics; IUCN, International Union for Conservation of Nature; LULC, Land Use Land Cover; OLI, Operational Land Imager; ROI, Regions Of Interest; RS, Remote Sensing; TM, Thematic Mapper.

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environmental database and represents crucial information for managing natural resources and guiding decision-making processes. This information constitutes a basic knowledge for applications ranging from the monitoring of forests and rangelands, the production of statistics, planning, biodiversity, climate change, to the fight against land degradation and desertification (Fahrig et al., 2011). In this context, Burel & Baudry (2002) mentioned that landscapes evolve even if they are little transformed by human activities and they respond to fluctuations in temperature, precipitation, fires, floods, etc. These evolutions cause various processes generating spatial heterogeneity which can contribute directly or indirectly to the degradation of landscapes and the loss of biodiversity (MEA, 2005). Particularly, human activities induced Land Use Land Cover (LULC) change, and caused biodiversity decline through the loss, alteration, and fragmentation of habitats (Elmqvist et al., 2016). In this context, a lot of researches have been carried out on detecting changes in LULC at different scales and on different topics (Singh, 1989; Carlson & Sanchez-Azofeifa, 1999; Käyhkö et al., 2011). The methods used are also numerous (Jensen, 2005) and; the results obtained vary according to the methods and data used in terms of quantity: the extent of changes detected and; in terms of quality: the nature of changes deduced (Berberoglu & Akin, 2009). As examples, Sharma et al. (2018) have applied the Geographical Information System (GIS) based integrated modeling tools to assess the biodiversity at a landscape scale in the district of Central Kalimantan, Indonesia. And they have used the Land Change Modeler (LCM) and InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Scenario Generator to design alternative LULC scenarios. In the Latin American metropolitan area, Colombia, Juanitaa et al. (2019) have evaluated the effects of past and future land cover changes in ecosystem services and biodiversity using Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) satellite images between 1986 and 2016. Then, past and future land cover changes were quantified following the post-classification comparison method. Results were tested via the construction of transition matrices. More specifically, different researches have been applied in Tunisia using GIS and Remote Sensing (RS) to assess and monitor LULC (Negm & Khebour, 2021). The Sousse region is one of the most biodiverse regions in the Tunisian sahel, and its ecosystems provide essential ecological services for human well-being at local, national and global scales. Nevertheless, it is faced to important land cover change over this decade (Boussema & Allouche, 2020). This research aims: i) to map the LULC changes that has been evolved between 2007 and 2017 using GIS and RS tools; ii) to analyze the landscape transformations of the Sousse region; iii) to characterize their effects on biodiversity; and iii) to propose a development plan for biodiversity conservation.

2. Study area

The study area is located in the Tunisian Sahel, on the east coast of Tunisia. It occupies a strategic location on the edge of the Mediterranean Sea (Fig. 1). Sousse covers an area of 2308 Km². It runs along the coast of the Sahel from northeast to southwest, between latitudes 35°44' and 36°13' North and between longitudes 10°11' and 10°41' West. It is limited to the north by the delegation of Enfidha and to the south by Sidi Abdelhamid. The region of Sousse is characterized by a Mediterranean climate, belonging to the lower semi-arid bioclimatic stage of the lower steppes of the north. The general average rainfall in Sousse region calculated for the period between 2007 and 2017 is in the order of 258.5 mm and; the annual average temperature is in the order of 18.6 °C.

The region of Sousse is known by the diversity of its landscapes: forest, coastline, rural, urban, industrial, and natural, but strongly linked to the variation of the environments that make up it

(Boussema & Allouche, 2020). Indeed, it is marked by natural sites characterized by the striking singularity of their composition and their richness enhanced by the coastal and marine fauna and flora (Fig. 2).

3. Sites of ecological richness in Sousse region

3.1. El Madfoun forest

The forest extends over 21 km along the coast, between Hergla and Salloum, with a variable width of 50 to 500 m, and occupies an area of about 450 ha (DGF, 2018). According to Hamdaoui (2015), this forest is one of the rare coastal forests in the country and constitutes a regional lung, a reserve of fauna and flora, a fixative element of the coastal dunes, and a distributor of a microclimate by its role of protecting the winds and through its influence on various climatic processes.

3.2. Halq El Mingel sebkha

Since 2006, the site has been classified as a Ramsar site according to the Ramsar Convention' or 'Wetlands Convention' adopted in Ramsar, Iran in February 1971 (Boussema et al., 2020a). This sebkha is located from 25 km northwest of Sousse city, its permanent surface is 1450 ha and it can reach 2050 ha during wet periods. It is divided into two parts; a northern part where the water is periodic and a southern part where the water is permanent. This segmentation is due to the road linking SidiBou Ali to Hergla which interrupts the exchange of water between the two parts (Chaggar & Boubaker, 2018).

3.3. Assat Ejriba sebkha

This sebkha is located on the north of the city of Hergla, it is limited to the east by the El Madfoun forest and the Mediterranean Sea, to the west by the Enfidha airport, to the north by the sebkha of Sidi Khalifa. It extends over 25 km from the north of Hergla to Bouficha with a variable width of 1 to 2 m. It is widely filled in rainy season and dry in summer; sheltering a multitude of fauna and flora (Hamdaoui, 2015).

3.4. Sousse sebkha

The sebkha is located in the south of Sousse city, and occupies an area of 62 ha. It is well located in an urban environment and close to the industrial area of Sidi Abdelhamid. It is a very fragile ecosystem which has become increasingly degraded, according to Ajimi (2019). Nevertheless, this ecosystem still represents an ecological potential that must be developed in order to restore and preserve the environmental quality of this area and restore the natural functions of the sebkha.

4. Materials and methods

4.1. Methodology

In this paper, we propose to present a multi-scalar methodological approach based on the use of remotely sensed data and GIS techniques to model LULC change of the Sousse region. Then, different steps are followed, namely: the acquisition of satellite images which constitutes the first step of collecting raster type data; pre-processing is a set of operations consisting in making raw data suitable for thematic analysis; the classification process to produce land cover maps and the post-classification step is necessary to validate the results of the automatic classification.

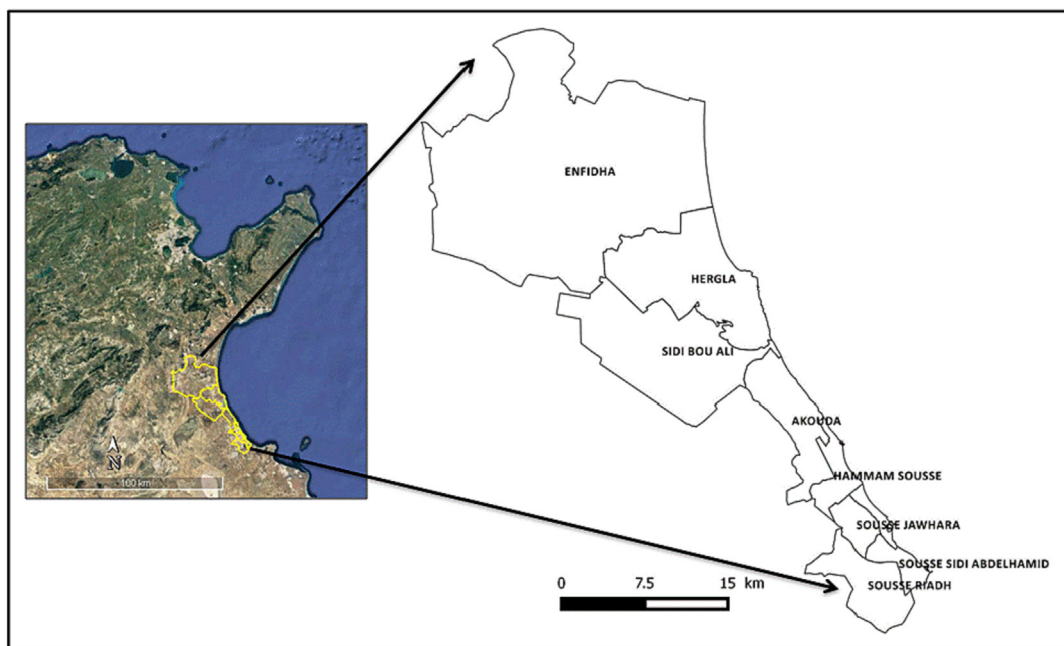


Fig. 1. Localization map of the study area.

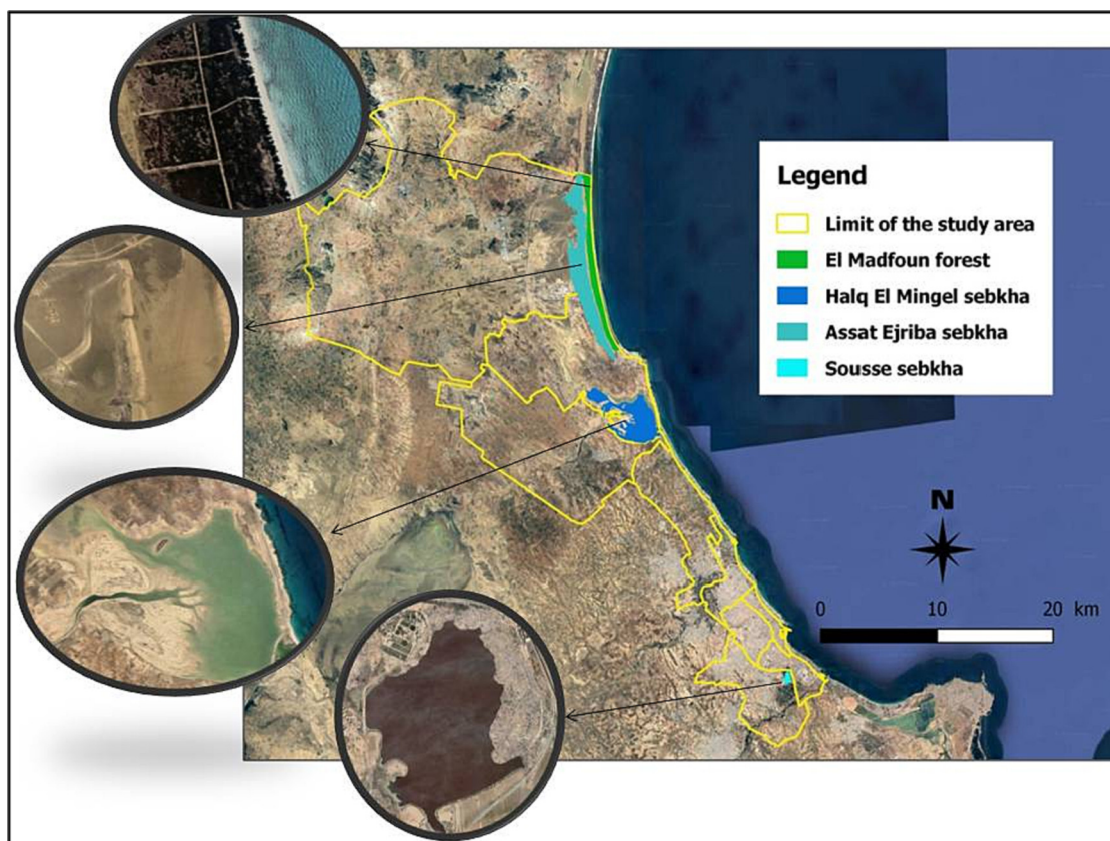


Fig. 2. Distribution map of ecological sites in the Sousse region (@Google Earth, 2022).

Validation is done with a field truth and a visual interpretation of the very high resolution data available on Google Earth ©. Fig. 3 shows the different steps followed to explain the change in land cover of the study area that has been occurred.

4.2. Remote Sensing data

Two satellite images have been selected and downloaded, Landsat 5 TM dated on 22/04/2007 and Landsat 8 OLI image recorded on

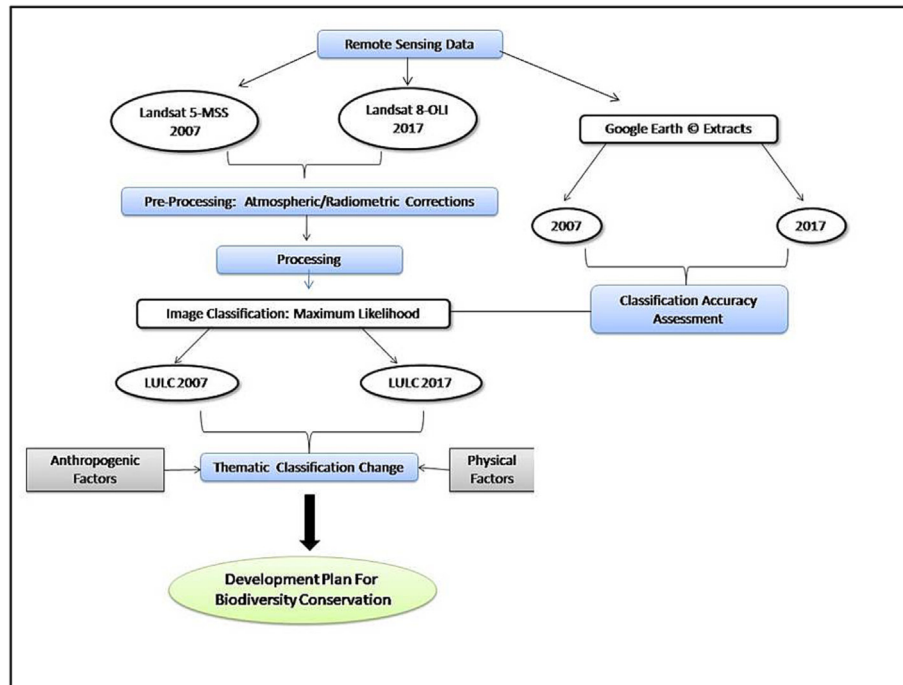


Fig. 3. Conceptual framework showing the overall process associated with this study.

01/04/2017. The Path is in the order of 119 and the Row is 035 for both images (Table 1).

4.3. Satellite data pre-processing

In order to make the image more readable, a primary correction step is required to eliminate any disturbance affecting the spectral signature of the various objects in the field. Pre-processing is a set of operations consisting in making raw data suitable for thematic analysis. According to Tidjani et al. (2009), these operations are performed on satellite images to correct or improve them geometrically and radiometrically. Thus, the Landsat images have been corrected using the Environment for Visualizing Images (ENVI®) 5.3 software with applying the « Radiometric Calibration » and

« Dark substruction » tools. ENVI is also used for all further processing of satellite data as an image processing system that benefits from many functions such as data transformations, filtering, classification, registration and geometric corrections, spectral analysis tools, and radar tools (Canty, 2014).

4.4. Image classification

For this step, 41 points were recorded during field work. After this, a total of 2718 and 2707 Regions Of Interest (ROIs) have been introduced, respectively for the 2007 174 and 2017 classification. Seven land cover classes have been predefined: urban, wetlands, olive groves, forest, cultivated soils, uncultivated soils and rangelands. The second step is based on the choice of the classification algorithm. Indeed, the Maximum Likelihood method has been used in this research considered one of the most efficient land use classification techniques (Boussema et al., 2020b).

4.5. Image post-classification

The functions “Sieve classes” and “Clump classes” were applied successively for the elimination of isolated pixels. While the “Majority/Minority Analysis” function has been used when the resulting classes present fragmented polygons (Congalton & Green, 2009).

4.6. Classification accuracy assessment

During this stage, it is important to identify the sources of error to be corrected in order to improve the quality of the classification (Congalton & Green, 2009). Validation is done in part by ground truth and by visual interpretation of a very high resolution data available on Google Earth®. Accuracy statistics for this study which includes overall accuracy and Kappa statistic for each image are given by ENVI® 4.8 software and presented in Tables 2 and 3.

Table 1
Time series characteristics of the LANDSAT satellite images used.

Characteristics	LANDSAT 5	LANDSAT 8
Launcher country	United States	United States
Launch year	1984	2013
Altitude (Km)	705	705
Sensor	TM	OLI
Number of bands	7	11
Spectral resolution (nm)	B (0.45 - 0.52) G (0.52 - 0.60) R (0.63 - 0.69) IR (0.76 - 0.90) MIR 1 (1.55-1.75) MIR 2 (2.08-2.35) TIRS(10.4-12.5)	B (0.45 - 0.51) G (0.53 - 0.59) R (0.64 - 0.67) IR (0.85 - 0.88) SWIR 1 (1.57 - 1.65) SWIR 2 (2.11 - 2.29) PAN (0.50 - 0.68) CIRUS (1.36 - 1.38) TIRS 1(10.60 - 11.19) TIRS 2(10.50 - 12.51)
Spatial resolution (m)	Multispectral : 30 Thermal : 120	Multispectral : 30 Thermal : 100 Panchromatic : 15
Image size (Km)	185 x 172	185 x 172
Repeatability (day)	16	16

(Source: <https://earthexplorer.usgs.gov/>).

Table 2
Confusion matrix of LULC 2007.

Actual class	Classification 2007	Predicted class									
		Urban	Wetlands	Olive GROVES	Forest	Cultivated soil	Uncultivated soil	Rangelands	Total	Proda.Acc.(%)	Omission(%)
Actual class	Terrain										
	Urban	811	0	0	0	0	2	0	813	100.00	0.00
	Wetlands	0	900	0	0	0	0	0	900	100.00	0.00
	Olive groves	0	0	351	0	13	0	0	364	89.54	10.46
	Forest	0	0	0	157	0	0	0	157	98.74	1.26
	Cultivated soil	0	0	41	2	317	0	0	360	91.09	8.91
	Uncultivated soil	0	0	0	0	0	66	0	66	97.06	2.94
	Rangelands	0	0	0	0	18	0	40	58	100.00	0.00
	Total	811	900	392	159	348	68	40	2718		
	User Acc.(%)	99.75	100.00	96.43	100.00	88.06	100.00	68.97			
Comission(%)		0.25	0.00	3.57	0.00	11.94	0.00	31.03			
Overall Accuracy(%)=97.20											
Kappa Coefficient=0.96											

Table 3
Confusion matrix of LULC 2017.

Actual class	Classification 2017	Predicted class									
		Urban	Wetlands	Olive groves	Forest	Cultivated soil	Uncultivated soil	Rangelands	Total	Proda.Acc.(%)	Omission(%)
Actual class	Terrain										
	Urban	811	0	0	0	0	6	0	817	100.00	0.00
	Wetlands	0	860	0	0	0	0	0	860	95.56	4.44
	Olive groves	0	0	177	0	88	0	0	265	45.15	54.85
	Forest	0	0	0	159	0	0	0	159	100.00	0.00
	Cultivated soil	0	0	188	0	241	0	0	429	69.25	30.75
	Uncultivated soil	0	40	0	0	19	62	0	121	91.18	8.82
	Rangelands	0	0	27	0	0	0	29	56	100.00	0.00
	Total	811	900	392	159	348	68	29	2718		
	User Acc.(%)	99.27	100.00	66.79	100.00	56.18	51.24	51.79			
Comission(%)		0.73	0.00	33.21	0.00	43.82	48.76	48.21			
Overall Accuracy(%)= 86.41											
Kappa Coefficient=0.82											

(Source: Data from satellite image processing 2007 and 2017).

4.7. Classification change matrix

Generally, two types of methods are distinguished: pre-classification methods that combine techniques for detecting changes before characterizing them, and post-classification methods (Van Oort, 2007) which perform individual image classification before detecting changes. Mas (2000) explained that there is no universal method for detecting change because it depends on the available data and the study's objectives. In our case, the post-classification method was used. As this is a diachronic study, the identification of the nature of the changes has become simple since we have the starting class and the arrival class of the zones having undergone a change. This approach is based on a change matrix (Coppin et al., 2004). In addition, the quality of the output is highly dependent on the quality of the input data (Mas, 2000), from which the input classification used must be as accurate as possible in order to limit the risk of error in the change map (Jensen, 2005). The analysis is based on the two land cover maps produced after classification, then on the application of the "Thematic Classification Change" option on ENVI® 5.3 software. Its editing is done under QGIS 2.18.

5. Results

5.1. LULC assessment of the Sousse region in 2007

The general area covered by olive groves and cultivated land is equal to 60.39 %, the region of Sousse was qualified as an agricultural region (Fig. 4). In 2007, the majority of the region was covered by olive groves (31.56 %), which are more concentrated in the north. Then, come cultivated soils occupying 28.83 % of the total area. They predominate in the northeast of the region; particularly in the city of Enfidha and Sidi Bouali. The distribution of urban

areas was not homogeneous and occupies 11.84 %, in 2007. In fact a rather clear dissymmetry is visible between the north and the south of the region. In the north, the built up areas have a very dispersed character. On the northwest side, an urban masses which correspond to the center of Enfidha city, and surrounded by small villages. However, in the middle, the two urban centers of Hergla and Sidi Bouali city are easily visible. In the south, the artificialization is more concentrated, and forms the largest urban center in the whole region which is the city of Sousse. On the one hand, from 2007, many parts of the coastline were artificialized, and taking the form of a "ribbon" parallel to the sea. It is the area between Sousse city and Hergla where a large number of construction were built on the seaside. On the other hand, there are parts of the coastline almost untouched by any artificialization, and located in the north; it is El Madfoun forest.

5.2. LULC assessment of the Sousse region in 2017

In 2017, the rangelands cover 23.38 %. They are located in the north near the olive groves; in the center near the wetlands and cultivated soils; and in the south near the urban and around the Sousse sebkha (Fig. 5). Cultivated soils occupy 21.70 %. They are located on the north side; more in the center; and at the level of the city of Enfidha. Towards the south, these fields are more and more fragmented with the appearance of rangelands areas inside.

The proportion of olive fields is equal to 18.77 %, and well fragmented. It is a division of olive groves associated with the insertion of small urban blocks. Urban areas occupy 14.14 % of the study area. In 2017, small urban patches of small areas were installed everywhere, and especially in olive and cultivated fields. In the northwest, the built up areas are more numerous, while in the center of the region, the ribbon habitat along the shoreline is clearly distinguishable. Uncultivated soils present 12.56 % of the total

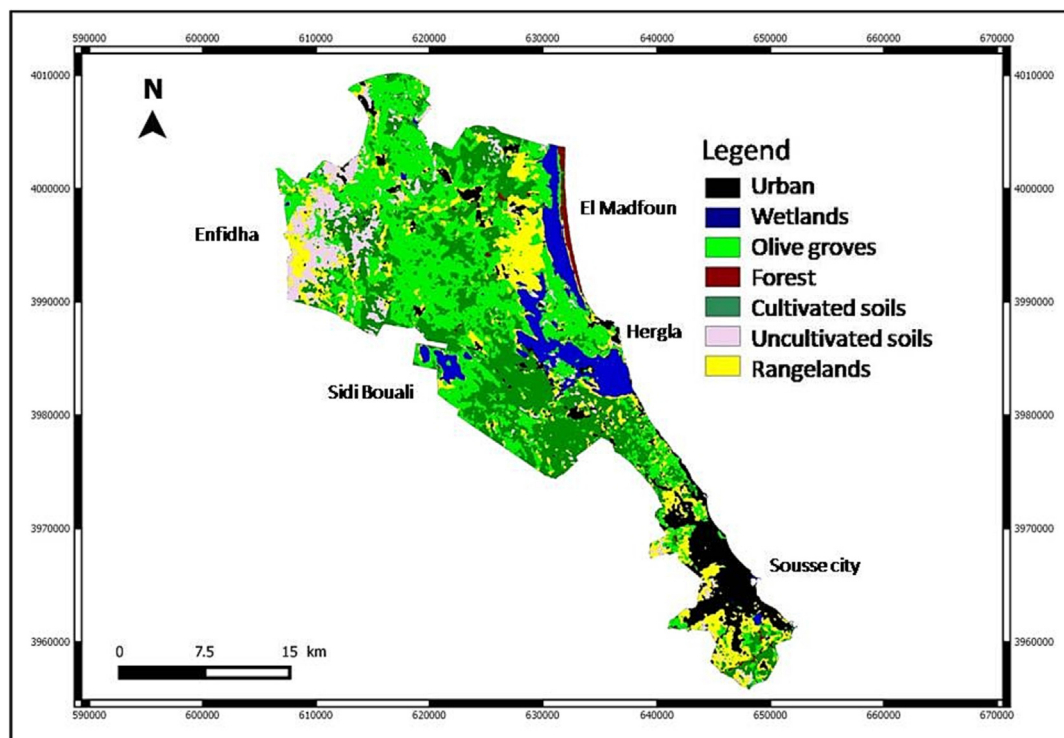


Fig. 4. LULC of the Sousse region in 2007.

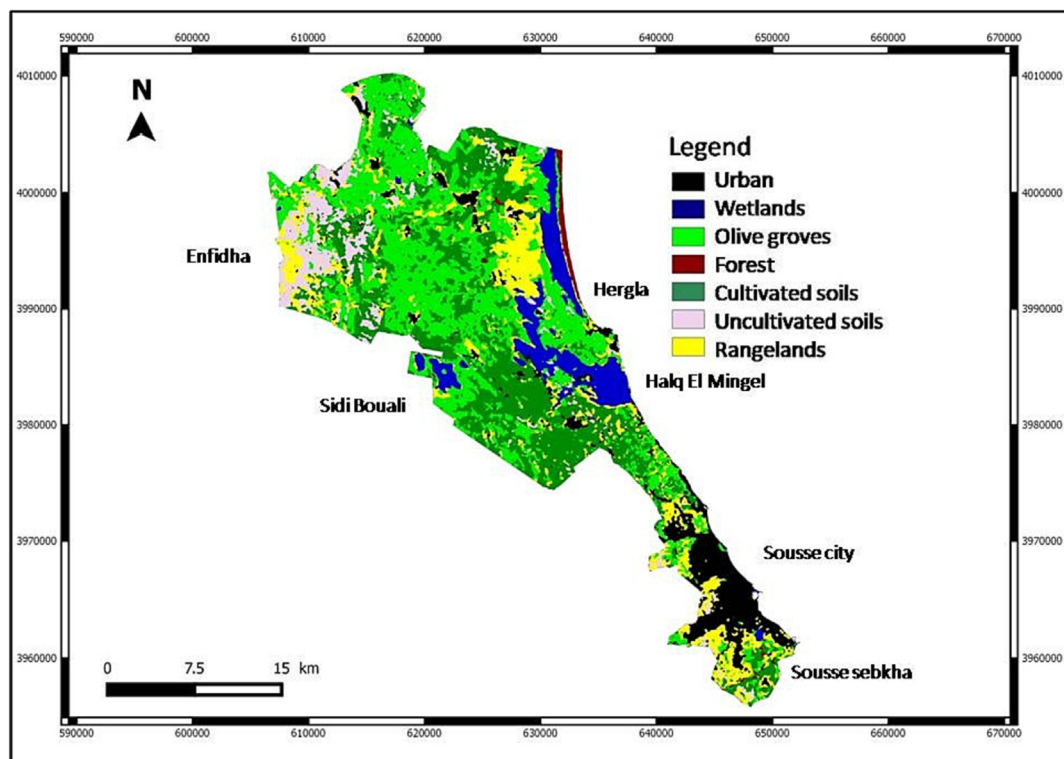


Fig. 5. LULC of the Sousse region in 2017.

area; and their persistence is noted around the sebkha of Halq El Mingel. In addition, wetlands are totally represented by sebkha and cover 7.50 %. Forests occupy only 1.95 %; and are located in the north and south of the study area. In 2017, the landscape of

the Sousse region is dominated by rangelands, cultivated soils and olive groves with unequal proportions. For urbanization, the dissymmetry between the north and the south is still visible with a high density on the southeast side.

5.3. Dynamics of landscape transformations in the Sousse region between 2007 and 2017

Table 4 presents in detail the areas of the different land cover classes during the period 2007–2017. Thus, this period is marked by a notable change in the land use patterns of the Sousse region. To understand the details of these transformations in the landscape, a change matrix (Table 5) has been established to explain the spatial and temporal evolution of the different land use classes.

The analysis of these spatio-temporal changes will help to deduce the nature of the landscape transformations in the study area. Based on the established change matrix, it is possible to identify three types of transformations that have affected the Sousse region: progression, regression, and stability.

Progression of built-up areas, equal to (+2.3 %) associated with densification of continuous urbanization along the coastal strip. As a result, continuity is being established from the city of Sousse to the city of Hergla. A clear trend of colonization of olive fields and agricultural areas by urban areas between 2007 and 2017 is well distinguished. Another important aspect to highlight is that olive groves and agricultural plots are much more fragmented than in 2007. Fig. 6 shows that the classes that have contributed to the increase in built-up areas are respectively the rangelands, cultivated soils and olive groves.

Progression of rangelands and uncultivated soils, represented successively by (+11.83 %) and (+5.43 %). This is explained by the abundance of land reserved for annual crops (vegetable crops) and biannual crops (field crops). Nevertheless, the gain in the uncultivated soils class is dependent on three classes: wetlands, olive groves, and rangelands, with almost equal proportions (Fig. 7). While the increase in rangeland areas results in a decrease in cultivated soils, olive fields, uncultivated soils and urban (Fig. 8).

Regression in the area of olive groves with the order of (– 12.79 %). This loss is mainly due to the growth of urban areas throughout the region. In particular, in the north and northwest of the study area, a significant transformation of olive fields into rangelands has been detected. This can be explained that in 2007, the fields included intercropping (under-olive crops) which did not exist in 2017. In contrast, the reduction in areas of olive groves has been replaced by the class of cultivated soils (Fig. 9).

Decrease in the area of cultivated soils equal to (–7.13 %). This period saw a significant loss of agricultural land to urban areas as a result of population growth and infrastructure development. However, throughout the north and center of the region, many agricultural plots have been converted into rangelands, which can be explained by the rotation system applied by farmers. In addition, the agricultural calendar may be one of the reasons for the change

in this type of land use. As for agricultural land; a large part has been transformed into olive trees and rangelands (Fig. 10).

Stability of the wetlands area, with a slight increase of (+0.25 %) which can be attributed to the significant rainfall recorded during April of the year 2017 equal to 366.8 mm.

Stability of the forest area, with a negligible increase of (+0.12 %) which is linked to the government policy justified by the reforestation work carried out by the General Directory of Forest in this region. The land cover classes that seem to be the most stable during this period are wetlands and forests occupying respectively about 7.4 % and 1.9 % of the general surface for the two dates analyzed. However, the other changes that have been occurred are really significant for a ten-year period, which is relatively short.

5.4. Factors influencing changes in LULC in the Sousse region between 2007 and 2017

From the changes that have occurred in the study area, it is necessary to characterize the main factors influencing the landscape transformations. So, the main drivers of environmental change are natural and anthropogenic factors that influence land use change. The latter have a more severe and lasting impact on change than physical factors. i) *Physical factors*; include geographical positioning and characteristics of natural conditions. As the study area is subject to a semi-arid climate, characterized by a relatively mild and humid winter and a hot and dry summer. Climatic variations during the study period show that precipitation is not regular throughout the year. Hence, farmers find themselves making use of pumped water which is characterized by salinity, and not suitable for some crops. Subsequently, the latter find themselves obliged to change their agricultural calendar and even to abandon their land. Soil erosion is the main trigger for the transformation of olive groves and rangelands into uncultivated soils. Also, marine erosion leads to the shrinking of wetlands. ii) *Anthropogenic factors*; result in a population increase. However, the demographic statistics drawn up by the National Institute of Statistics (INS) show that in 2007 the population in the region of Sousse is equal to 333.6 Thousand inhabitants (INS, 2007), but in 2017 the number has increased to be equal to 416.3 Thousand inhabitants (INS, 2017). This is due to the increase in the urban environment from 2007 to 2017. Thus, government economic development plans, urbanization and industrialization have influenced land use patterns and led to the loss of agricultural land. They encourage new promoters to settle in the region and build continuously by giving them all the priorities and facilities. As a result, a lot of agricultural land has been converted in urban development plans to become eligible for construction.

Table 4
Changes in land cover in the Sousse region between 2007 and 2017.

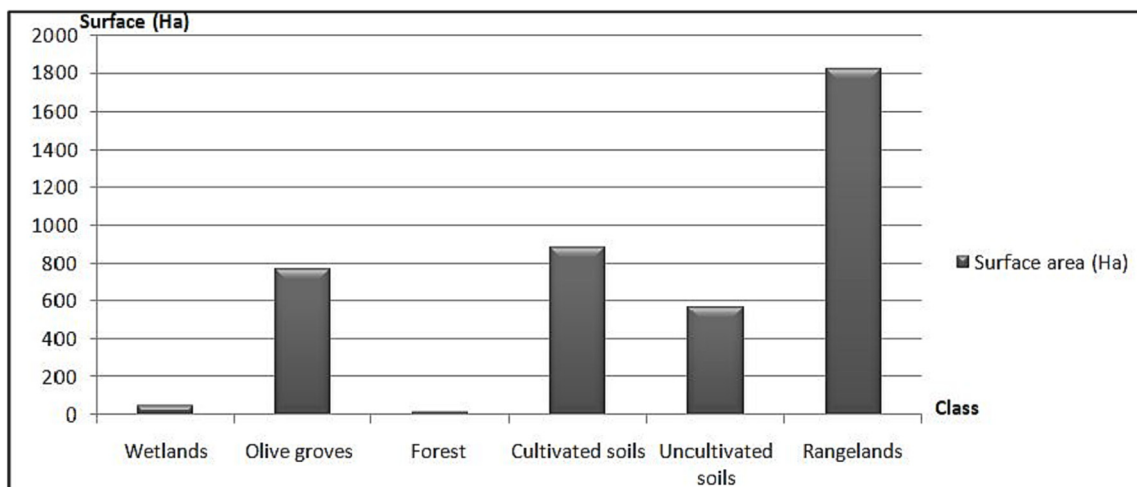
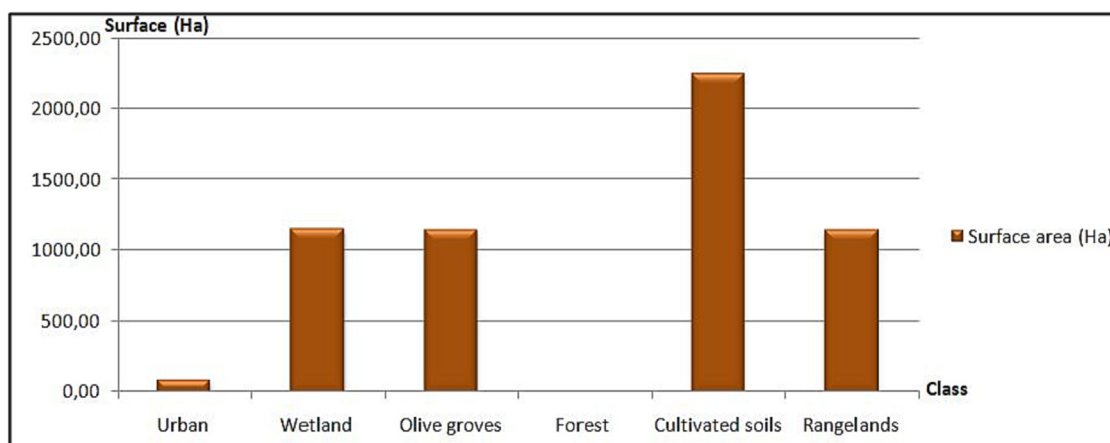
Land cover classes	2007		2017		Evolution rate (%)
	Surface area (ha)	Surface rate (%)	Surface area (ha)	Surface rate (%)	
Urban	8677	11.84	10359	14.14	2.3
Wetlands	5314	7.25	5495	7.50	0.25
Olive groves	23122	31.56	13750	18.77	-12.79
Forest	1339	1.83	1431	1.95	0.12
Cultivated soils	21124	28.83	15897	21.70	-7.3
Uncultivated soils	5227	7.13	9200	12.56	5.43
Rangelands	8461	11.55	17132	23.38	11.83
TOTAL	73264	100	73264	100	-

(Source: Data from satellite image processing 2007 and 2017).

Table 5

Land cover change matrix in the Sousse region from 2007 to 2017.

		Land cover 2017 (Ha)							
		Urban	Wetlands	Olive groves	Forest	Cultivated soils	Uncultivated soils	Rangelands	Total
Land cover 2007 (Ha)	Urban	6104	45	768	13	883	564	1818	10195
	Wetlands	9	4013	49	8	762	7	587	5435
	Olive groves	41	2	10210	8	3139	133	71	13604
	Forest	28	3	54	478	418	1	422	1404
	Cultivated soils	15	29	3918	192	10357	31	1180	15722
	Uncultivated soils	86	1153	1146	1	2255	3266	1144	9051
	Rangelands	500	114	3061	43	7134	1106	4911	16869
	Total	6796	5367	19354	747	25122	5126	10214	72726

**Fig. 6.** Contribution of the different land cover classes to the expansion of urban areas in 2007–2017.**Fig. 7.** Contribution of the different land cover classes to the increase of uncultivated soils between 2007 and 2017.

5.5. Impacts of LULC changes in biodiversity

On the one hand, the decline in cultivated areas has two negative aspects on biodiversity, and this is due to a potential reduction in the connection of habitat elements favorable to plant and animal species. On the other hand, agricultural areas have a buffer effect between artificial or urbanized areas and natural and semi-natural areas, so that a decrease in agricultural areas makes natural areas vulnerable to changes in land use. Indeed, for urban areas, we are talking about the fragmentation of landscapes which occurs when human activities modify the landscape by creating barriers to the dispersal of species. For example, built-up areas; major

equipment; and terrestrial transport infrastructure slows down or even blocks the movement of species which is essential for their survival. In fact, the terms of reference for urban development must be more demanding with respect to biodiversity, allowing it to be preserved, and improving the quality of life and social link.

5.6. Proposal for actions in favor of biodiversity in the Sousse region

Specific developments are proposed to enhance biodiversity and make the study area susceptible to more fauna and flora species. These proposals from north to south are presented in Fig. 11 by:

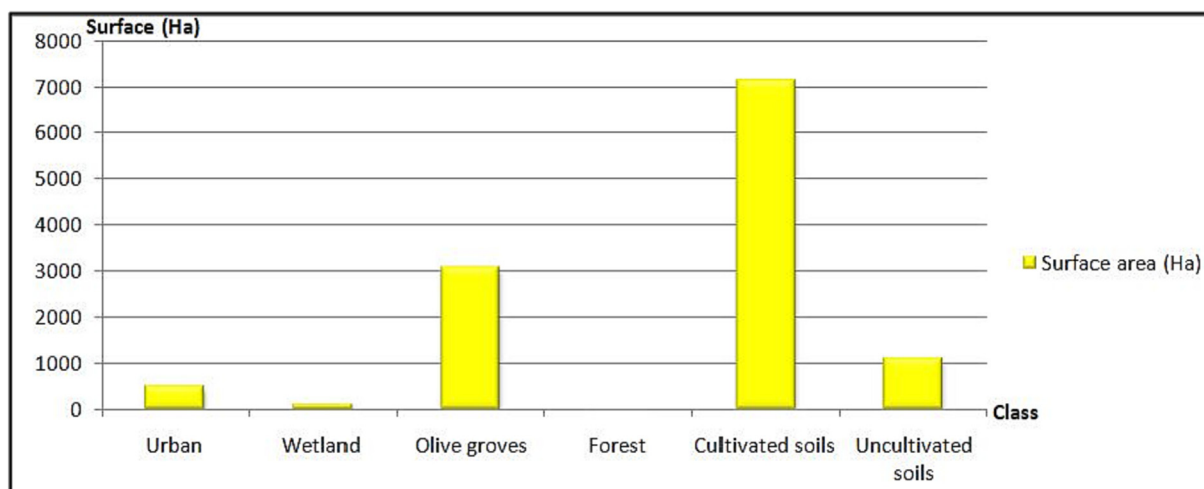


Fig. 8. Contribution of the different land cover classes to the increase of rangelands in 2007–2017.

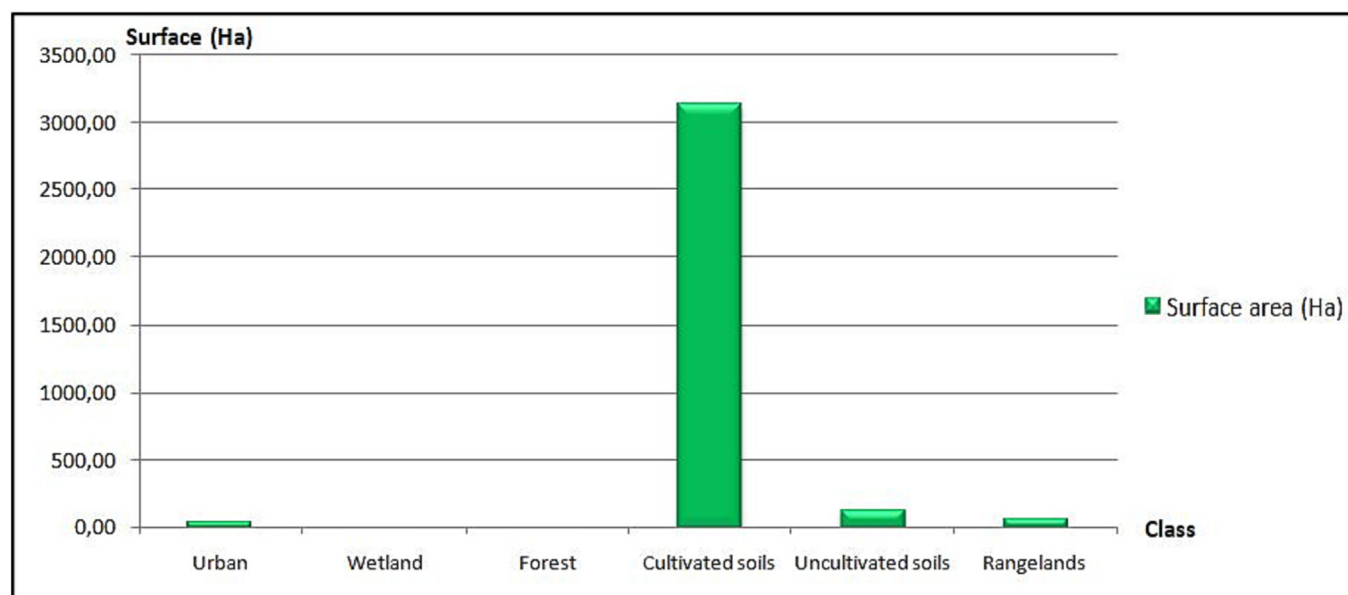


Fig. 9. Redistribution of olive groves into four classes in 2007–2017.

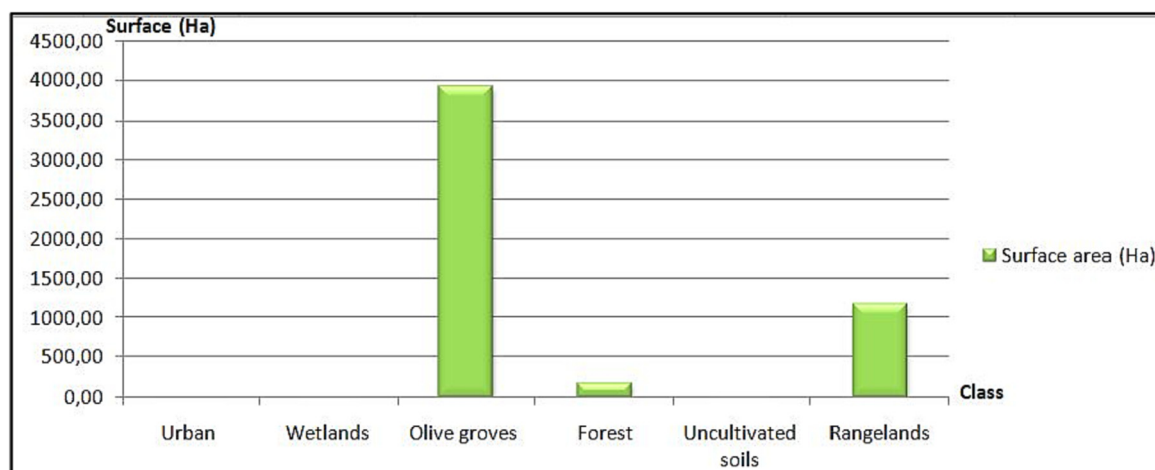


Fig. 10. Redistribution of cultivated soils into three classes in 2007–2017.

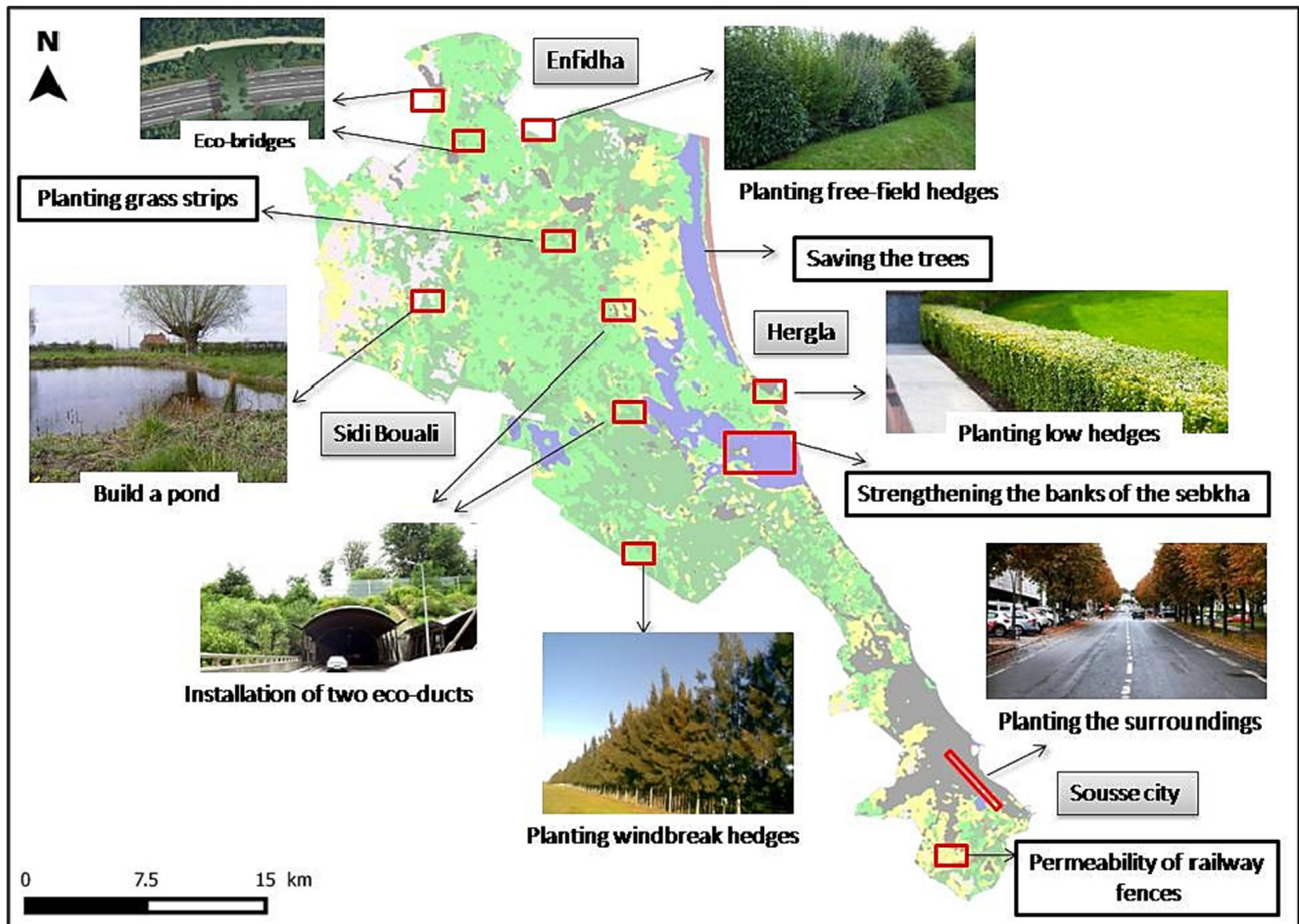


Fig. 11. Development plan for biodiversity conservation in the Sousse region.

a) Installation of two eco-bridges; can be constructed allowing the passage of small and medium fauna at the level of the regional road, with 2 m in width and 8 m in length.

b) Planting free-field hedges; in the rural environment north-east of Enfidha, having a height of 2 m and a width of 0.8 m. It will have an ecological and anti-erosive role. The composition of the selected species may include *Quercus coccifera*; *Quercus ilex*; *Juniperus*; and *Tamarix*.

c) Saving the trees of El Madfoun forest; is a challenge in terms of maintaining biodiversity and local landscape identities.

d) Planting grass strips; with 5 m wide, sown or spontaneous, on the edge of cultivated plots in the agricultural area in the central eastern part of the Enfidha region. Legumes such as Clover and Lucerne; can be usefully combined with Ray-grass. And which are interesting for insects (honey bees) and birds (areas of refuge, rest, food and reproduction).

e) Building a pond; northwest of Enfidha, near the forest of Ain Garci; 1.2 m deep allowing plants to take root with amphibious vegetation such as: *Juncetea bufonii*, *Bidentetea tripartitae*; and *Nasturtietea officinalis*.

f) Installation of two eco-ducts; at Enfidha at the level of the Highway (A1) and the national road (RN1). These passages will combine a fluvial flow and a transition zone for terrestrial fauna.

g) Planting low hedges; around the subdivisions created from the Land Housing Agency at the southern entrance of Hergla city.

h) Strengthening of the banks of Halq El Mingel's sebkha; by the planting of *Acacias cyanophylla* associated with *Pins maritime*

to protect it against erosion and mitigate the phenomenon of sea spray.

i) Planting windbreak hedges; in the crop fields of Sidi Bouali city which comprise a deciduous species; *Populus*, and a persistent species; the *Cupressus* to break the power of the wind and protect crops.

j) Planting of the edges of the Boulevard of Environment; located at the southern entrance of Sousse city. Evergreen trees are chosen as alignment trees to shade the passage in this boulevard, especially in summer, composed of *Brachychiton populneus*. The latter is altered with a shrub-type plant such as *Euphorbia pulcherrima* to favor the installation of small fauna.

k) Permeability of railway fences; located south of the city of Sousse which allow most species to pass under and the larger animals to walk on it.

6. Discussions

For the purpose of this study, Landsat images were used for different reasons: a) they are free to download; b) their spatial resolution is equal to 30 m, which is appropriate with the scale of the study area; and c) they have been available since 1987, hence their major usefulness for a diachronic study of LULC changes. However, the development of new generations of very high spatial resolution satellites (SPOT 7, Pléiades, Sentinel 2, etc.); will therefore be very interesting to exploit them especially at local scales. Indeed, the

establishment of a multi-scalar landscape approach has revealed changes in the land use of the study area. In general, three types of change have been concluded: a) the growth of built-up areas; b) the progress of rangelands; and c) the regression of the areas occupied by olive groves and cultivated soils. These results are generally similar to those obtained for other study areas: in Europe (MacDonald et al., 2000) and in the Mediterranean region (Falcucci et al., 2007; Boussema & Allouche, 2020; Boussema et al., 2021). According to Forman (1995); Burel & Baudry (2002); and Farina (2011) change is a feature in natural systems that can take many forms and levels. So, different drivers of change can be identified, such as natural disturbance processes and those caused by anthropogenic activities. This might be as a result of natural or human effects including climate change, urban sprawl and agricultural activities which are adequate with the results study of Bobbink et al. (2006); Mitsch et al. (2009); and Chenchouni et al. (2015). Firstly, the change observed in the Sousse region can be explained by the increase in the built-up areas and population rate. Secondly, erosion, lack of water for irrigation, cultivation practices, and soil amendments contribute to the artificialization dynamics of the study area. Hence the observed change factors are mainly related to anthropogenic and climatic factors. Previous research that assessed land cover changes and their effect on biodiversity have shown the big relation between ecological services provided by biodiversity with the increases in urbanization (Long et al., 2014; Peng et al., 2017; Boussema et al., 2020b); losses of forest (Tolessa et al., 2017; Rodríguez-Echeverry et al., 2018) or wetlands (Siles et al., 2018; Boussema et al., 2020a); growth of cultivated areas (Abulizi et al., 2017) and forest plantations (Montoya-Tangarife et al., 2017). From Mendoza (2014), landscape dynamics is the phenomenon resulting from the relationships between natural and anthropogenic processes in a territorial unit. Increasingly, this process limits the various quality habitats for wildlife and therefore increases the risks of erosion and loss of biodiversity (Boussema et al., 2020a). The study area is marked by natural sites characterized by its composition and richness (Boussema & Allouche, 2020). However, the established industries have weakened the surrounding landscapes, polluted the natural environment. They are still a source of environmental degradation, and harm to human health. Economic development and urbanization, have almost all damaged the environment, disrupted landscapes and land use patterns, and aggravated erosion phenomena (Chaggar & Boubaker, 2018). For its part, wildlife has suffered from the most impact due to population expansion and LULC changes. Indeed, Tunisian authorities work with the International Union for Conservation of Nature (IUCN) to develop a National Red Lists for Species and Ecosystems and it has recently developed a National Biodiversity Strategy and Action Plans 2018–2030. Moreover, referring to the list of endangered species in Tunisia (IUCN, 2021), several species appears related to the study area such as: *Numenius arquata*; *Marmaronetta angustirostri*; *Lepus capensis*; and *Atelerix algirus*; listed on the global IUCN Red List as Critically Endangered and Vulnerable. Therefore, it is important to use emerging GIS and RS technologies to implement land management strategies to conserve sensitive sites and species ranges. The Republic of Tunisia, located in northern Africa, faces various environmental challenges caused by anthropogenic practices such as overgrazing, deforestation, and desertification. The conversion of natural ecosystems is the major cause of plant biodiversity loss (You et al., 2016). Floods and droughts are expected to occur more frequently in coastal, desert, and urban areas, which may result in crop losses and food insecurity. The LULC assessment help to detect the expansion of weeds, from example in Kairouan region located in the west of Sousse, Sayari et al. (2021) have approved that more than 60 % of the Al Alem irrigated perimeter was infested

by *Solanum elaeagnifolium* which contributes to the reduction of the biodiversity of cultivated plant species.

7. Conclusions

Space technologies allowed us to study landscape changes in the Sousse region and enabled us to assess its state and its variations between 2007 and 2017 thanks to space science. In addition, knowledge of the evolution of land use and landscape structures appears essential for understanding the spatial distribution and evolution of species in these types of environments. Sousse has undergone significant landscape transformations. In particular, urbanization has played a major role in this dynamic landscape; the surface area of built-up spaces increased from 11.84 % in 2007 to 14.14 % in 2017. Cultivated areas has declined and varied from 28.83 % in 2007 to 21.70 % in 2017. However, this reduction plays a negative role in biodiversity, a reduction of the plant biodiversity of natural species by reducing the areas of grassland and uncultivated areas and of cultivated species by the reduction of agricultural areas and the increase of weed invasion. Then, this reduction will play an important role in the loss of animal species and food security. In this context, the LULC change analysis represents an essential study for any territorial planning proposal as a guide to the conservation, enhancement and protection of landscapes. It provides accurate information on local threats, the costs of action and will guide decision makers in their sustainable planning strategies. Research developed recently upstream of the design of a Green and Blue Infrastructure for the conservation of biodiversity in the Sousse region (Boussema et al., 2022).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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