Agroecology Initiative

Technical Report

# The Eco-Landscape Approach for Landscape Restoration

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Agroecology

Zahra Shiri and Quang Bao Le

November, 2024

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This report starts by defining key concepts related to landscape, including landscape scale, ecosystem services, mosaics, and fragmentation, establishing a foundation for understanding ecosystem functionality and biodiversity in complex landscapes. It then applies this framework to the agroecology living lab in Kef and Siliana, Tunisia, highlighting the region's ecosystem diversity, including its rich flora and fauna. Following this, an assessment of natural habitat dynamics and landscape metrics is conducted at both the living lab and the transect levels in Kef and Siliana. These methods aim to inform a set of recommendations for effective landscape restoration and sustainable land management in the region.

# Theory and key concepts

## Landscape definitions

The concept of landscape has evolved over time, the word landscape derived from German and Dutch origins in the Middle Ages as “landschaft” and “landschap” meaning "shoveled land", it has been given several definitions and interpretations. Landscape covered in multifaced fields and explored various disciplines including, geography (e.g. relationships between natural and cultural processes within a spatial context), ecology (e.g. the interactions between biophysical soil, water, biota and vegetation), arts (e.g. the inspiration of beauty, the aesthetic value, the ambience of the landscape), sociology (e.g. social interactions and cultural practices), anthropology (landscapes as human phenomena with constructs such as infrastructure, land uses, electoral and political constituencies) and history.

Defining the term ‘landscape’ can be challenging due to the different functions, roles, values and stakeholders associated with the term. The term landscape can be defined as a socio-ecological system consisting of a mosaic of natural and/or human-modified ecosystems, with a characteristic pattern of topography, vegetation, land use and human settlements, influenced by the ecological, historical, economic and cultural processes and activities of a region (Scherr et al 2013). Landscape can also be defined as a holistic view of resources management (the definition of Global Landscapes Forum 2016), or as a set of spatial and ecological features that guide conservation and development objectives. It can also refer to governance and other social interactions and mechanisms that minimize trade-offs between conservation and development (Redford et al. 2003).

In summary, landscapes are heterogeneous mosaics composed of interactive units or place-based systems (a spatial limitation) that result from interactions between people, land, institutions and values. These interactions provide the ecological services and social and economic relationships on which people depend.

The recent literature is associating landscape to a set of key words, as seen in Figure 1, related to inter and multidisciplinary fields.

## Landscape scale

Landscape scale refers to the spatial extent or size of an area being studied or restored, there is no exact definition of ‘landscape scale’; rather, it is a set of different scales used to delineate the landscape. The ‘right scale’ may need to take into account the perception of the people involved and natural or cultural characteristics.

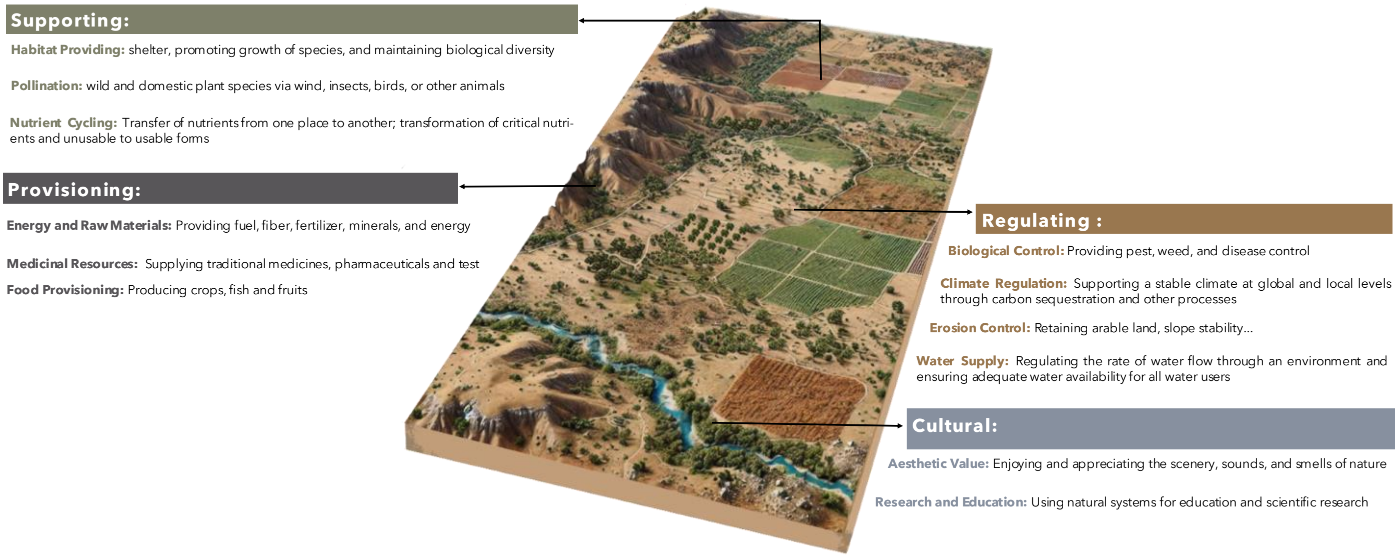
Examples of landscape scales:

- The landscape scale can be defined as an administrative or climatic limitation: local, regional and cross-continental (Mediterranean), country, continental to global scale.
- The scale of the landscape is ‘as far as the eye can see’, as defined by the Oxford English Dictionary as “all the visible features of an area of land, often considered in terms of their aesthetic appeal”.
- The landscape scale can be divided into the spatial structure of a landscape, and the analysis can be carried out at patch level (e.g. plots), class level (e.g. forest, agricultural, urban) or landscape level (all classes merged together) the scale which would include sufficient elements to provide ecosystem services, and ecosystem function to allow for multifunctionality of interactions.

**Figure 1.** Landscape in recent literature word cloud

## Ecosystem services

The sustainable functioning of different landscape elements and their ecosystems provides benefits known as ecosystem services (Figure 2). There is a close link between the health and the ecosystems’ synergy, quality and sustainability. In a landscape, the emergence of new interactions between species promotes connections between ecological functions and increases the quality and the value of ecosystem services. The structure and management of landscapes (spatial complexity and configuration) significantly influence ecosystem services (i.e. pollination, pest control, water quality, disease control, and aesthetic value), which are essential for human well-being (Qiu, 2019). Changes in composition, configuration, and connectivity of landscapes can have a positive impact on the capacity, demand, and flow of ecosystem services. (Mitchell, 2021). Therefore, the integration of ecosystem services and landscape management is necessary to address threats such as erosion, soil degradation, and food insecurity.


**Supporting:**

**Habitat Providing:** shelter, promoting growth of species, and maintaining biological diversity

**Pollination:** wild and domestic plant species via wind, insects, birds, or other animals

**Nutrient Cycling:** Transfer of nutrients from one place to another; transformation of critical nutrients and unusable to usable forms

**Provisioning:**

**Energy and Raw Materials:** Providing fuel, fiber, fertilizer, minerals, and energy

**Medicinal Resources:** Supplying traditional medicines, pharmaceuticals and test

**Food Provisioning:** Producing crops, fish and fruits

**Regulating :**

**Biological Control:** Providing pest, weed, and disease control

**Climate Regulation:** Supporting a stable climate at global and local levels through carbon sequestration and other processes

**Erosion Control:** Retaining arable land, slope stability...

**Water Supply:** Regulating the rate of water flow through an environment and ensuring adequate water availability for all water users

**Cultural:**

**Aesthetic Value:** Enjoying and appreciating the scenery, sounds, and smells of nature

**Research and Education:** Using natural systems for education and scientific research

**Figure 2** Ecosystem services classification in a dry landscape (own elaboration)

## Landscape mosaics

'Mosaic' is a term that has become increasingly familiar in ecology research field with the development of landscape ecology. It is associated with the recognition of the spatial heterogeneity of ecological systems. Landscape mosaics (Figure 3) are more or less heterogeneous in time and space, showing landscapes that are more or less fragmented or connected.

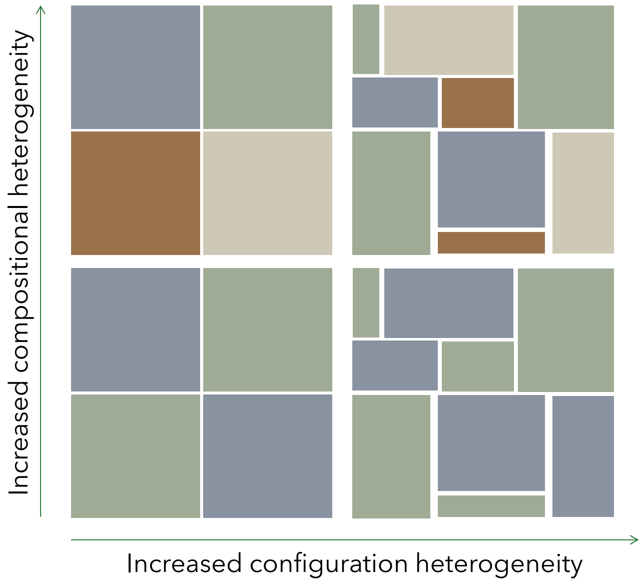


**Figure.3** Distinction between spatial heterogeneities of configuration and composition (own elaboration based on Fahrig et al. 2011)

The heterogeneity of a mosaic is assessed in terms of the composition and configuration of the landscape elements:

- Compositional heterogeneity increases with the number of elements or habitats present, whether rangelands, grassland, crops, buildings or ponds. In other words, its diversity increases.
- Configurational heterogeneity increases with the complexity of the spatial arrangement of these elements. It is lower when the elements are large and unfragmented, and higher when they are small, of varied shapes and intertwined.

A heterogeneous landscape is a complex network where:

- The diversity of habitats offers resources of different kinds that will meet the ecological requirements of a large number of species: feeding sites, breeding sites, nesting sites or refuge areas that will be able to accommodate them in unfavorable periods. Maintaining semi-natural elements in agricultural landscapes contributes to this diversity and increases the number of ecological niches in the landscape.
- Ecological interactions between environments are more intense, which can make it easier for species to move around and find food or breeding sites.

In the case of forests and grasslands, an increasing heterogeneity can lead to habitat fragmentation and the disappearance of certain species.

# Landscape fragmentation

Fragmentation is the reduction and division of habitat into several patches that are more or less isolated from each other separated by an unfavorable surrounding environment (Figure 4).

The loss of habitat has negative effects on biodiversity, because a population needs a minimum area of habitat to survive. By increasing the distance between habitat patches fragmentation directly affects the dispersal behavior of individuals. Certain landscape elements act as a barrier to the normal movement of individuals.

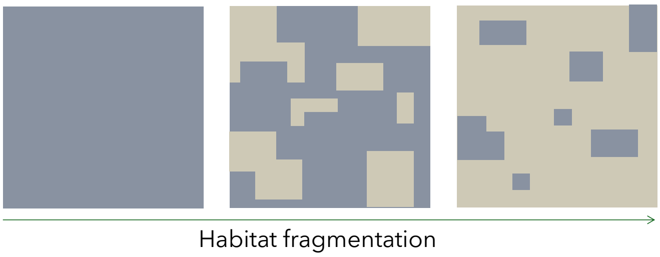


**Figure.4** Habitat fragmentation (own elaboration based on Fahrig, 2003)

# Landscape connectivity

The maintenance of populations in a heterogeneous and fragmented landscape depends on the colonization of habitat patches. This colonization is only possible when habitat patches are sufficiently connected to allow individuals to disperse. That requires the maintenance of connection between landscape structural elements (patch, corridor and matrix), known as the patch-corridor-matrix model (Figure 5).

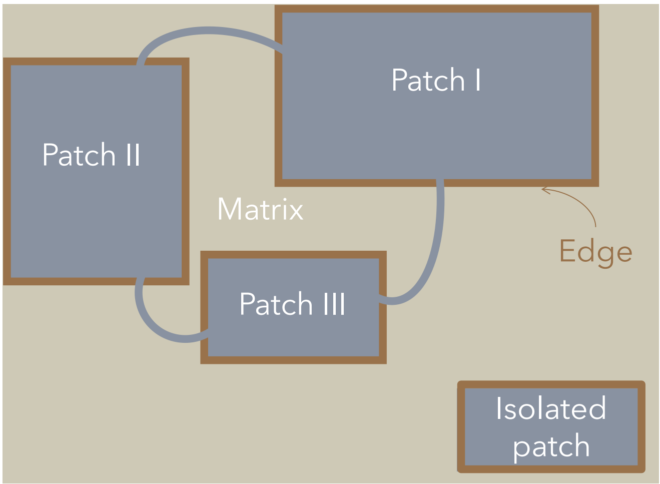


**Figure.5** Patch-corridor-matrix model (own elaboration based on Bogaert, 2000).

## Eco-landscape approach

Landscape approach has evolved from 19th-century landscape geography to encompass various applications. The term 'landscape approach' has been applied in many different frameworks, and has emerged as a holistic approach to the complex challenges of achieving sustainability in the management of natural resources, often encompassing and representing different theories, views and methods. It highlights multifunctional, integrated planning that includes ecological, social and economic dimensions (Reed et al. 2015).

Integrating ecology into integrated landscape approaches can improve understanding, planning and monitoring, while revealing the trade-offs and synergies between conservation, human–nature relations, environmental health and human well-being, development, communication and acceptance of ecological knowledge exchange across different planning sectors (Reed et al. 2015).

In the field of landscape ecology, which is really the ecology of land diversity, the landscape approach has played a major role in the emergence of this approach in the sciences related to land use/land cover. The main characteristic of the 'land areas' considered in the landscape approach is that they are made up of identifiable and distinct units (or 'patches') which are often found within a 'matrix'. This idea is often expressed by the word 'mosaic'.

To ensure that a heterogeneous landscape functions properly, it is necessary to establish links and interactions between the different landscape units (natural environment, river, plot, semi-natural environment, urban), which leads to functional diversity. *The eco-landscape approach aims to enhance positive interactions and reduce negative interactions by optimizing the arrangement of elements. It is equally essential that there is some form of integration between these elements. Thus, the approach is the basis for the transition of a landscape to sustainable land-use pattern (State of Sustainable Initiatives 2016).*

For the example of agricultural landscape, it is composed of a multitude of plots and intermediary spaces, whose dimensions, shapes and arrangements vary both in space and time, as a function of crops succession and agricultural activities. The constraints of farms, in relation to their production methods, and the characteristics of the environment, in relation to the distribution of soils and groundwater, are linked to these arrangements. These mosaics are linked to the socio-economic and socio-ecological aspects of the studied landscape.

One of the promoted system transformation approaches is agroecology, globally in the top of R/D agenda, combining two concepts, 'agronomic and ecological'. It relies on the enhancement of biodiversity and related ecosystem services to support agricultural production and depends on biological interactions for the design and management of farming systems in agricultural landscapes. Agroecology transition requires improving the connectivity and synergy between agricultural fields and semi-natural habitats (Jeanneret et al., 2021).

The concept of Agroecological infrastructure (AEI) was developed by the International Organization for Biological and Integrated Pest Management (IOPMB) in 1992. With regard to biological diversity and the landscape, the directive specifies that ecological compensation areas must cover a minimum of 5% of the total area of the farm (excluding forests). Agroecological infrastructures include areas that receive no fertilizer or pesticide inputs (hedges, forest edges, ponds, meadows) (Pointereau et al., 2007).

AEI provides ecosystem services and can help to improve production by reducing the need for chemical and energy inputs. Hedgerows and grassed areas help to regulate water flows, reduce erosion and store water in the soil. Reducing erosion and slowing down the flow of water also helps to improve water quality, by promoting the degradation of organic molecules by micro-organisms, denitrification and the absorption of nutrients by plants, leading to a reduction in the nitrogen, phosphorus and pesticide content of run-off water. AEI are important habitats for biodiversity. They play a major role in maintaining or restoring the biological connectivity creating biological corridors (Pointereau et al., 2007).

# Eco-Landscape approach application in the OneCGIAR Initiative on Agroecology

There is a growing focus on promoting agroecological landscape transitions, i.e., the transition from current agricultural landscapes to new stages of development, with improvements in the principles of agroecology. In Tunisia, an ongoing initiative led by OneCGIAR focuses on agroecological transitions. The focal zone of the intervention for the implementation and demonstration of landscape transitions is the region composed of the Kef and Siliana governorates. This zone covers six different sites (i.e., the focal community areas), which together form the Agroecology Living Lab Landscape (ALL) (Kesra, Chouarnia, Elles, Sers, Rhahla, and Hammam Biadha), a concept adopted by the project's research team (Shiri et al, 2024).

Under this long-term research strategy, which remains in development, the effective transition of the current agricultural landscape system towards improved agroecology should be based on a deep understanding of the key landscape change processes that occurred in the past.

To successfully implement and apply an Eco-Landscape approach, a mixed data collection method was adopted starting with field visits, grey literature review, literature review, news, social media, documentaries and surveys during the period between February 2023 and May 2024.

## Ecosystem diversity in Kef-Siliana transect

The ecosystems in Kef-Siliana (Figure 6-9) include: Terrestrial ecosystems (Forest ecosystem, cultivated areas, Meadows), Freshwater ecosystems (Lakes, Rivers, Streams), artificial ecosystems (Urban ecosystems, Agricultural ecosystems, Reservoir or dam ecosystems), and two Ramsar sites (the Saddine-Kef Nature Reserve and Ain Dahab-Siliana).

**Figure 6.** Agroforestry landscape (Zahra Shiri, 2023)

**Figure 7.** Sylvo pastoral landscape (Zahra Shiri, 2023)

**Figure 8.** Forest and cropland patches (Zahra Shiri, 2024)

**Figure 9.** Flowers patches mosaic (Zahra Shiri, 2024)

### Flora diversity

The Flora in Kef-Siliana transect can be divided into the three major categories below. For each category, a non-exhaustive list of species is presented showing the major present species in the area.

Sylvopastoral resources and natural forests are mainly composed of Aleppo Pine, Holm Oak, along with other forest species of great ecological value such as maple, thuja, red juniper, wild olive, mastic, juniper, and Cupressus sempervirens *f. numidica*, which is found in three locations between Jebel Serj and the Kesra plateau.

The grazing lands are divided into forest grazing lands and steppe grazing lands: Forest grazing lands consist of scrublands covering vast areas (scrublands of Holm Oak, rosemary, dyss, Spanish broom, thyme, heather, spiny broom, rockroses, wild pistachio) with substitute grass formations (ermes and lawns) and the infiltration of a group of steppe species (alfa, sparta, Erinacea anthyllis, Diplotaxis harra).

Oleolentiscus formations based on wild olive trees with or without carob trees.

## Fauna diversity

Mammals of the Kef-Siliana transect are typical of the karstic zone. It is important to highlight the presence of bats, in underground wetlands (species undefined, but probably Pipistrellus), as well as the crested porcupine *Hystrix cristata* (found in caves), wild boar *Sus scrofa*, mongoose *Herpestes ichneumon*, striped hyena *Hyaena hyaena*, Cape hare *Lepus capensis*, Algerian hedgehog *Erinaceus algirus*, red fox Vulpes *vulpes atlantica*, weasel *Mustela nivalis*, and common genet Genetta. Birds are sensitive indicators of biological richness and environmental conditions. The birds reported in literature in the Kef-Siliana transect up to this day are numerous, including residents, winter visitors, summer visitors, and migratory species. The avifauna includes several nesting passerines, primarily associated with rugged areas, notably the Moussier's Redstart (*Phoenicurus moussieri*), one of the very rare bird species endemics to North Africa, and the Black Wheatear (Oenanthe leucura). It is highly probable that various raptors nest on the rocky cliffs of Djebel Serdj and other mountains in the region, including the Golden Eagle (Aquila chrysaetos) and the Egyptian Vulture (Neophron percnopterus). The figure 10 presents wildlife animals in Kef-Siliana transect.

Despite the richness of the study area, biodiversity in the Kef-Siliana transect is facing significant degradation due to various factors (fragmentation, urbanisation, pollution, excessive hunting, forest fires, intensification of agriculture). This ongoing degradation is leading to a reduction in species richness and a change in plant cover.

FAUNA DIVERSITY (mammals)

FAUNA DIVERSITY (birds)

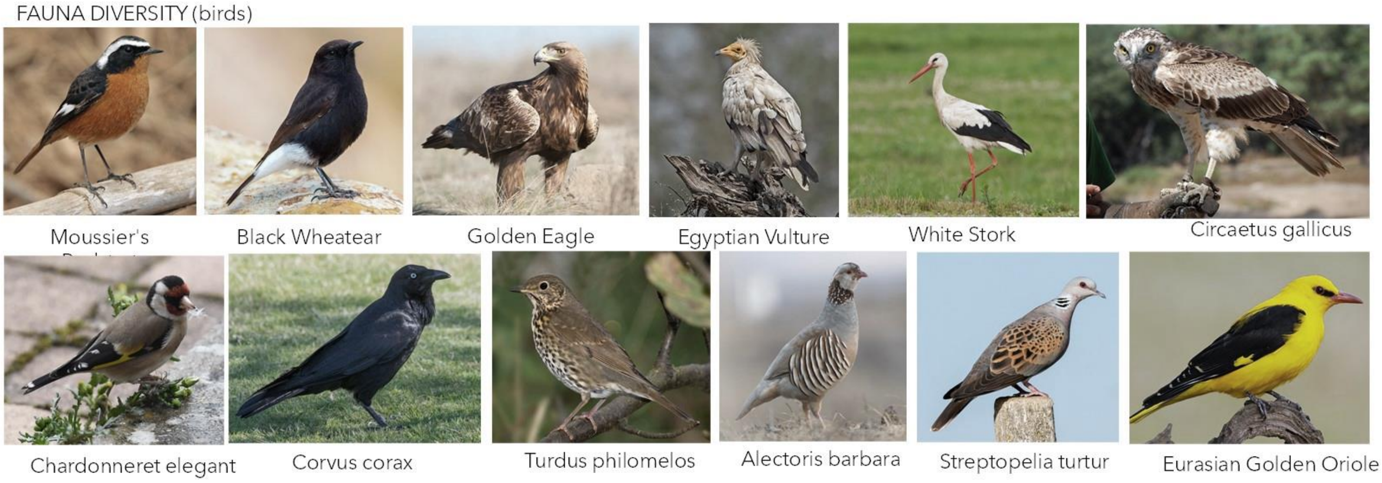


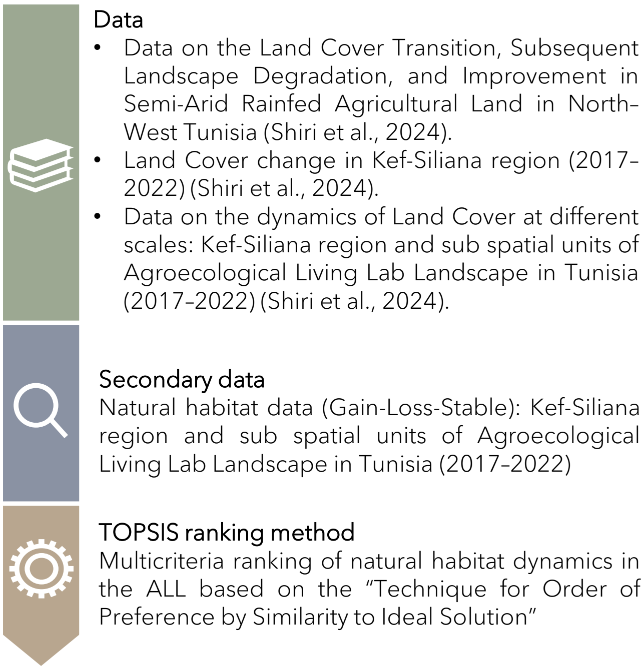
**Figure 10.** Fauna diversity in Kef-Siliana transect (based on diverse sources: Google images, Social Media)

# Methods for natural habitat dynamics assessment

In order to characterize the natural habitat dynamics in Kef-Siliana transect and the Tunisian Agroecology Living Landscape (ALL) of CGIAR Agroecology Initiative, a land cover change map with a resolution of 0.1 ha was produced. For this analysis, the number of land cover types was limited to tow natural habitat (forest and rangeland) and other land cover categories (cropland, water, bare land and urban)

Land cover change (LCC) is often a fundamental shift in a landscape that drives further transformations, collectively forming a landscape transition. A land conversion can have ecological impacts that are either negative, such as when forests are converted to urban or farmland, or positive, such as shifting from monoculture to agroforestry systems with enhanced biological practices. Additionally, the spatial distribution of LCC reflects the extent of ecological connectivity within the landscape, such as the establishment or disruption of green corridors, which is crucial for assessing environmental health and integrity (Shiri et al., 2024).

To rank and compare the 6 units of ALL, based on natural habitat dynamics, a mixed method combining spatial analysis and statistical calculations was used (Figure 11).



Data
- Data on the Land Cover Transition, Subsequent Landscape Degradation, and Improvement in Semi-Arid Rainfed Agricultural Land in North-West Tunisia (Shiri et al., 2024).
- Land Cover change in Kef-Siliana region (2017-2022) (Shiri et al., 2024).
- Data on the dynamics of Land Cover at different scales: Kef-Siliana region and sub spatial units of Agroecological Living Lab Landscape in Tunisia (2017–2022) (Shiri et al., 2024).

Secondary data
Natural habitat data (Gain-Loss-Stable): Kef-Siliana region and sub spatial units of Agroecological Living Lab Landscape in Tunisia (2017–2022)

TOPSIS ranking method
Multicriteria ranking of natural habitat dynamics in the ALL based on the "Technique for Order of Preference by Similarity to Ideal Solution"

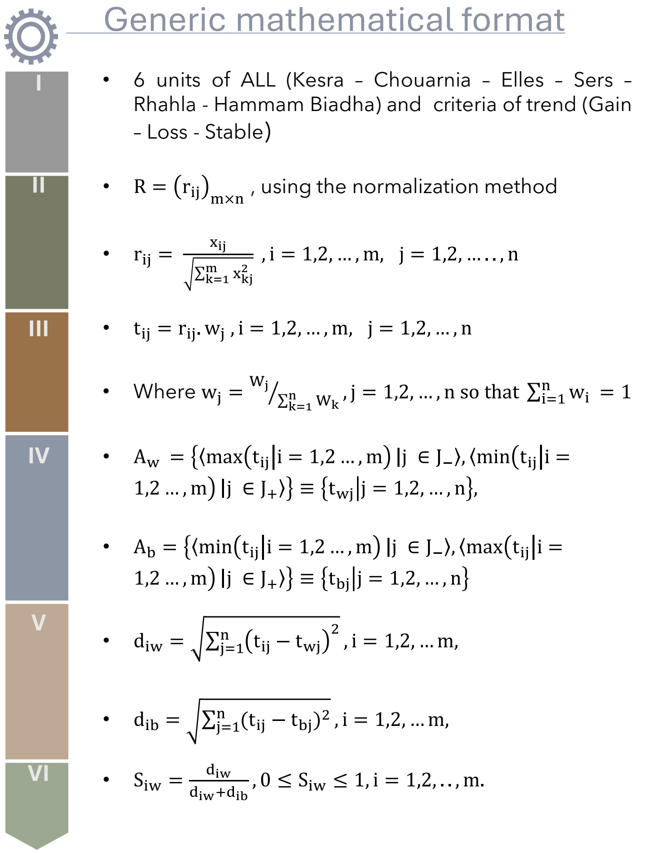
**Figure 11.** Flowchart of connected methods–tasks

The technique for ordering preference by similarity to ideal solution was first introduced by (Hwang & Yoon, 1981) as an alternative for solving multi-attribute decision problems (El Allaki et al., 2019) where a decision maker needs to take a decision based on different attributes (or indicators).

The method is part of the techniques known as multi-criteria for decision making (MCDM) (Ramón-Canul et al., 2020). It is particularly used for ranking or selecting one or more options (or alternatives) from a finite number of options (El Allaki et al., 2019) with respect to multiple criteria (Yeh, 2002).

This method involves seven steps as follow (Figure 12):

I. Creating an evaluation matrix consisting of m alternatives and n criteria.
II. Normalize the created matrix.
III. Calculate the weighted normalized decision matrix: weights for each evaluation criteria can be specified in an ex-ante manner, thus reflecting the preferences of the evaluator for a criterion or another. Equal weights can be used as default. The sum of all weights should be equal to 1.
IV. Determine the ideal and anti-ideal solutions according to this logic.
V. Calculate the Euclidian-distance between the target alternative and the worst condition, and the distance between the target alternative and the best condition.
VI. For each alternative, we calculate the relative closeness to the ideal solution allowing the ranking of available options from the best to the worst.
VII. We rank all alternatives based on their respective scores.



Generic mathematical format

- 6 units of ALL (Kesra – Chouarnia – Elles – Sers – Rhahla - Hammam Biadha) and criteria of trend (Gain – Loss - Stable)
- $R = (r_{ij})_{m\times n}$ , using the normalization method
- $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}, i = 1,2,\dots,m,\ \ j = 1,2,\dots\dots,n$
- $t_{ij} = r_{ij}.w_j, i = 1,2,\dots,m,\ \ j = 1,2,\dots,n$
- Where $w_j = {}^{w_j}/_{\sum_{k=1}^{n} w_k}, j = 1,2,\dots,n$ so that $\sum_{i=1}^{n} w_i = 1$
- $A_w = \{\langle \max(t_{ij} | i = 1,2\dots,m) | j \in J_-\rangle, \langle \min(t_{ij} | i = 1,2\dots,m) | j \in J_+\rangle\} \equiv \{t_{wj} | j = 1,2,\dots,n\},$
- $A_b = \{\langle \min(t_{ij} | i = 1,2\dots,m) | j \in J_-\rangle, \langle \max(t_{ij} | i = 1,2\dots,m) | j \in J_+\rangle\} \equiv \{t_{bj} | j = 1,2,\dots,n\}$
- $d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2}, i = 1,2,\dots m,$
- $d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2}, i = 1,2,\dots m,$
- $S_{iw} = \frac{d_{iw}}{d_{iw}+d_{ib}}, 0 \le S_{iw} \le 1, i = 1,2,..,m.$

**Figure.12** TOPSIS Steps and mathematical format

# Insights from the Natural Habitat Dynamics Assessment

Forests and rangelands are the key parts of the ecosystem that capture carbon and provide excellent habitats for wildlife, however, they face anthropogenic pressures increasingly. In the Kef-Siliana region, the natural area, as identified earlier, amounts to a major sector of the landscape backing to 62.6% in 2017 and going up to 64.1% in 2022 (Figure 13). The increasing area of natural habitats is expected to bring a positive impact, as there has been an increase in the total area coverage from 612,661.6 ha in 2017 to 627,819.7 ha in 2022. In 2017, the areas with forests convered 10.3% of the natural habitat while the rangelands dominated with 89.7%. In 2022, the portion of forest areas increased to 11.1% and the areas on rangelands had slightly come down to 88.9% of the total.

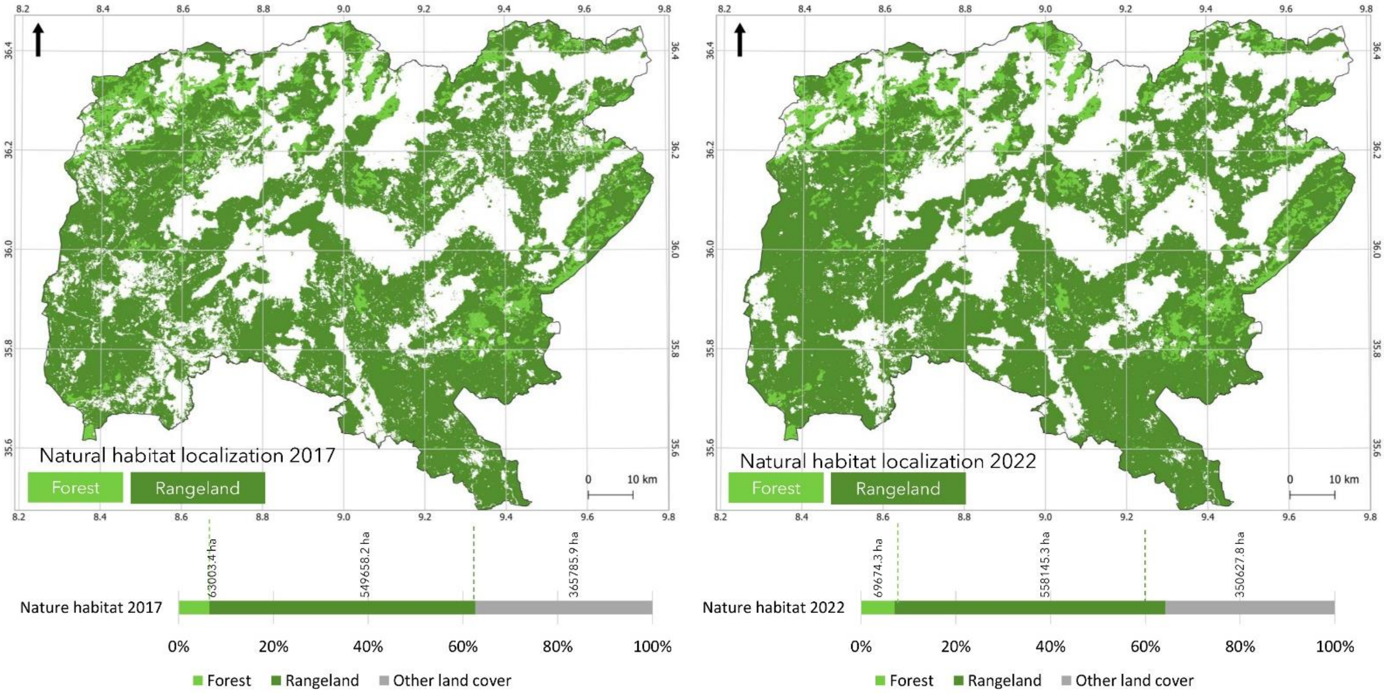


**Figure 13.** Natural habitat maps in Kef-Siliana transect [2017-2022]

The Kef-Siliana transect between the years of 2017 and 2022 experimented different natural habitat changes, the loss and the gain of habitat taking place among them (Figure 14). A total of 59,640 ha of natural habitat were converted to areas of different land cover including the replacement of forested areas by urban areas and the conversion of rangelands into agricultural plots. Apart from this, the study area had a substantial gain of 81,618 ha reflecting a net Natural habitat increase during that period.

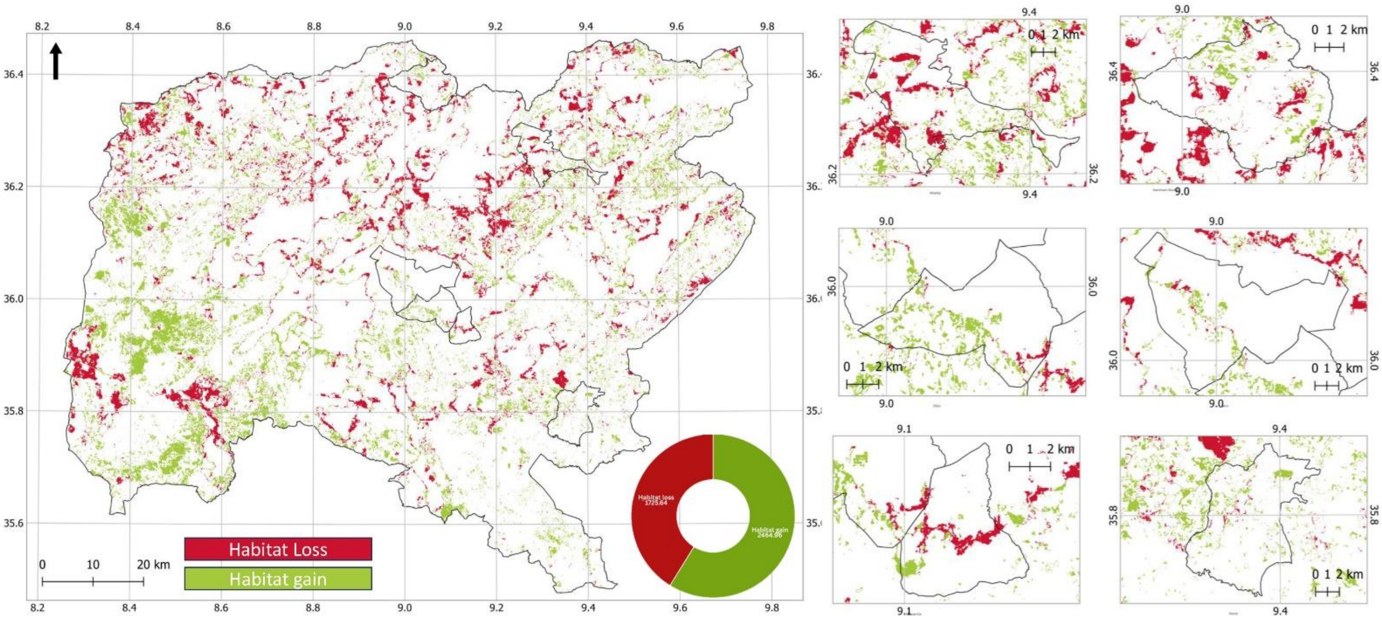
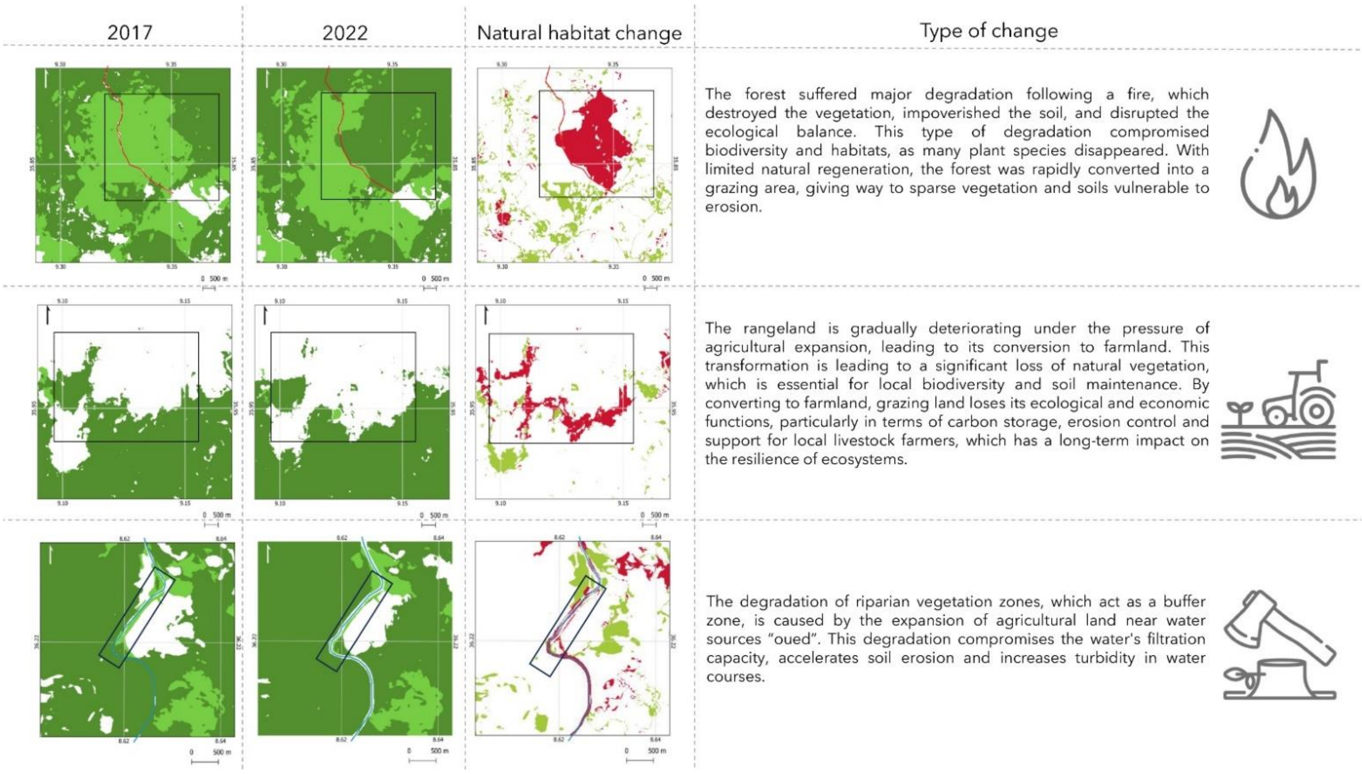


**Figure.14** Natural habitat degradation map at Kef-Siliana region and sub spatial units of Agroecological Living Lab Landscape in Tunisia between 2017 and 2022.

The ALL has been tracking the same main trends, also differences inter-ALL units have been noticed. Thus, Elles reached the greatest increase (23%) while Kesra and Chouarnia increased the least (6%). The areas of Chouarnia and Rhahla are the ones that showed the highest habitat loss of 13%, yet the stable habitat percentages were the highest overall, being 73% at Elles and 93% at Kesra.

Habitat loss, in the Kef-Siliana transect, is due to many interrelated factors, which is a result of the complex interrelationship between human activities and the local ecosystem. Agricultural expansion is one of the main driving factors. Furthermore, the lack of soil and forest cover due to overgrazing and deforestation is yet another environmental problem that leads to the degradation. Naturally and human-caused fires are a strong factor towards losing habitats, destroy large amounts of vegetation, which in turn shifts the ecosystem and limits its diversity. In Figure 15, three examples of natural habitat loss, causes, localization, type are detailed.



The forest suffered major degradation following a fire, which destroyed the vegetation, impoverished the soil, and disrupted the ecological balance. This type of degradation compromised biodiversity and habitats, as many plant species disappeared. With limited natural regeneration, the forest was rapidly converted into a grazing area, giving way to sparse vegetation and soils vulnerable to erosion.

The rangeland is gradually deteriorating under the pressure of agricultural expansion, leading to its conversion to farmland. This transformation is leading to a significant loss of natural vegetation, which is essential for local biodiversity and soil maintenance. By converting to farmland, grazing land loses its ecological and economic functions, particularly in terms of carbon storage, erosion control and support for local livestock farmers, which has a long-term impact on the resilience of ecosystems.

The degradation of riparian vegetation zones, which act as a buffer zone, is caused by the expansion of agricultural land near water sources "oued". This degradation compromises the water's filtration capacity, accelerates soil erosion and increases turbidity in water courses.

**Figure.15** Natural habitat loss, examples from transect Kef-Siliana

Based on the Pi (the multi-criteria TOPSIS parameter), the six units of ALLs can be ranked as seen in Table 1. Given the same weight of 0.33 for the three ranking variables (Improvement, Stability, Degradation), Rhahla presents the lowest score (of 0.25) in other words, the most threatened unit of ALL while Kesra exhibits the highest score (of 0.66). More details about the score can be found in the Figure 16 where the score (Pi) is shown in y axis and the axis x shows a pie chart of each unit of ALLs, ranked from left to right.

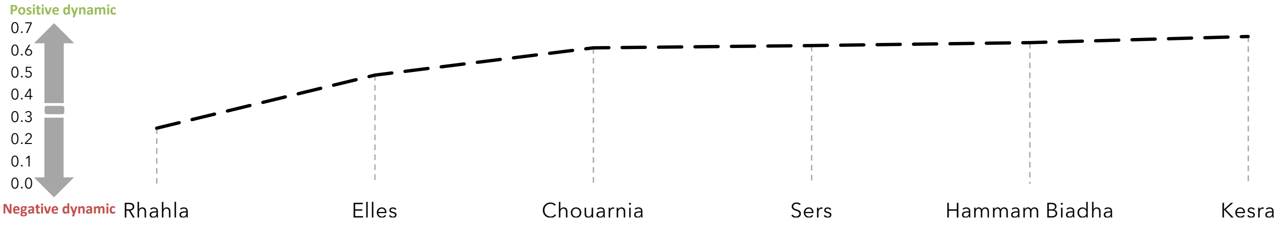


**Figure.16** ALL ranking chart

**Table.1** TOPSIS ranking score per ALL unit

| Agroecology Living Landscape Lab | Pi | Rank |
|---|---|---|
| Rhahla | 0.25 | 6 |
| Elles | 0.49 | 5 |
| Chouarnia | 0.61 | 4 |
| Sers | 0.62 | 3 |
| Hammam Biadha | 0.64 | 2 |
| Kesra | 0.66 | 1 |

# Landscape metrics assessment

Landscape metrics are essential tools in assessing landscape ecology and evaluating agroecosystems, habitat function, and regulatory roles within ecosystems.

These metrics, besides helping to understand these landscape features in patch size, shape, distribution, and connectivity, allow one to apprehend how these features affect ecological processes such as the movement of species, resource distribution, and habitat quality. The quantifying of these patterns by landscape metrics enables ecologists to monitor landscape changes through time, assess the effects of fragmentation, and evaluate ecological consequences of land cover changes (Shiri et al., 2024).

## Kef-Siliana Transect level

In landscape ecology, the Shannon Index, Shannon Equitability, and Simpson Index can be adopted to quantify the diversity of different land cover types by treating the various classes of land cover as "patchs" and their respective area proportions as "abundance". This is how these metrics are useful for land cover assessments.

### Shannon's diversity index (H)

To assess regional land-cover diversity in each unit of ALL, we calculated the Shannon index. Shannon's diversity index is a measure of the variety of land uses in an area. Unit of measure is dimensionless index that indicates the number of different classes. A diversity index is a mathematical measure of species variety in a community or land uses variety in a certain area. It provides more information than the richness or the number of existing land uses, it also takes the relative abundances of different land use types into account (Konopiński, 2020). Calculating the index to each pixel and its neighbours in a raster map of land cover follow the following formula.

$$H = -\sum_{i=1}^{S} p_i \, Ln \, p_i$$

- $P_i$ is the relative abundance of each group of land cover type of study area.

This index can theoretically range from 0, meaning that the grid is homogeneous, with no diversity (i.e., only pixels of a single land-use type present) to infinite, meaning maximum heterogeneity (i.e., each pixel of a different land-use type).

### Shannon Equitability (EH)

Shannon Equitability, is a measure of evenness, quantifies how evenly land cover types are distributed in a landscape (Hossain et al., 2017).

$$EH = {}^{H}/_{S}$$

- S Total number of patches.

Equitability assumes a value between 0 and 1 with 1 being complete evenness.

### Simpson Index (D)

The Simpson Index (D) is a measure of diversity that reflects the probability that two patches randomly selected, belong to the same land cover type (He et al., 2005).

$$D = \sum_{i=1}^{S} P_i^{2}$$

- $P_i$ is proportion of each group of land cover type of study area by the i-th category
- S Total number of patches.

The Simpson Index, D, ranges between 0 and 1. A low value of D, close to 0, reflects high diversity. Conversely, when D approaches 1, this indicates low diversity and represents the dominance of one category.

### Main results for Kef-Siliana Transect

The analysis of landscape metrics in the Kef-Siliana transect from 2017 to 2022 reveals a decline in critical indicators of biodiversity and habitat distribution (Table 2).

Shannon's diversity index (H) decreased from 1.142 to 1, indicating a reduction in overall habitat heterogeneity within the landscape. Likewise, Shannon Equitability (EH), which quantifies the evenness of habitat distribution, declined from 0.587 to 0.517, signifying greater disparity and uneven representation among land cover types. The Simpson Index (D), a measure that reflects the probability of encountering diverse habitat types and accounts for species dominance, also dropped from 0.6 to 0.561, suggesting a reduction in habitat heterogeneity and an increase in the prevalence of dominant land cover categories.

These trends underscore a shift toward reduced structural complexity and decreased ecological evenness, raising concerns about the potential impacts on biodiversity conservation and ecosystem functionality within the region.

**Table 2.** Landscape metrics results for Kef-Siliana transect

| | 2017 | 2022 | Trend |
|---|---|---|---|
| Shannon's diversity index (H) | 1.142 | 1 | ⬇ |
| Shannon Equitability (EH) | 0.587 | 0.517 | ⬇ |
| Simpson Index (D) | 0.6 | 0.561 | ⬇ |

## ALL level

### Patch Cohesion Index (COHESION)

Patch Cohesion Index (COHESION) is an index that measures the physical connectedness of the corresponding patch type. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected (Opdam et al., 2003).

$$\mathrm{COHESION} = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{ij}\sqrt{a_{ij}}}\right] * \left[1 - \frac{1}{\sqrt{A}}\right]^{-1} * 100$$

- $P_{ij}$ perimeter of patch ij in terms of number of pixels surfaces.
- $a_{ij}$ area of patch ij in terms of number of pixels.
- $A$ total number of pixels in the landscape.

COHESION can theoretically vary from 0 to 100. The index approaches 0 as the proportion of the landscape made up of the focal class decreases and becomes more and more subdivided and less and less physically connected.

### Landscape division (D)

Landscape division (D) is defined as the probability that two randomly chosen places in the landscape under investigation are not situated in the same undissected patch (Jaeger, 2000). Landscape division (D) range from 0 to 1, D= 0 when the landscape consists of single patch, and D =1, value when the landscape is maximally subdivided.

$$D = \left[1 - \sum_{j=1}^{n}\left(\frac{a_{ij}}{A}\right)^{2}\right]$$

- $a_{ij}$ area of patch ij in terms of number of pixels.
- $A$ total number of pixels in the landscape.

### Largest Patch Index (LPI)

Index of the dominant patch corresponding to the relation between the surface of the largest patch of the class and the total area of the buffer zone. The index is between 0% (larger size, smaller patch) and 100% (landscape consisting of one patch of larger size) (Talukdar et al., 2021).

$$\mathrm{LPI} = \left(\frac{\mathrm{LP}}{\mathrm{A}}\right) * 100$$

- $LP$ Largest Patch Area.
- $A$ Total Landscape Area.

High values of LPI indicate dominance of the patch type. Low LPI values indicate fragmentation where no single patch type dominates the landscape.

### Main results for ALL

The landscape metrics for Chouarnia, Elles, Sers, Hammam Biadha, Rhahla, and Kesra provide deeper insights into the structure and fragmentation of both forest and rangeland ecosystems from 2017 to 2022 (Table 3). At the landscape scale, Shannon's diversity index shows negative values across all ALL units, indicating low diversity, with Hammam Biadha (-0.057) being the least negative and suggesting a relatively more diverse landscape compared to Elles (-0.201), which reflects minimal diversity.

In the forest scale metrics, the Patch Cohesion Index (COHESION) reveals significant fragmentation, with Sers exhibiting a high positive value (9.642), indicating strong cohesion and patch aggregation, while the other regions show low or negative cohesion values. The Landscape Division (D) index highlights Sers as the most fragmented landscape (D = 1), while Chouarnia and Rhahla indicate a more contiguous landscape.

**Table 3.** Landscape metrics results for ALL

| | Chouarnia | Elles | Sers | Hammam Biadha | Rhahla | Kesra |
|---|---|---|---|---|---|---|
| Landscape scale | | | | | | |
| Shannon's diversity index (2017-2022) | -0.063 | -0.201 | -0.179 | -0.057 | -0.071 | -0.026 |
| | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| Forest scale | | | | | | |
| Patch Cohesion Index (2017-2022) | -0.431 | -0.373 | 9.642 | -0.004 | -0.009 | -0.005 |
| | ↓ | ↓ | ↑ | ↓ | ↓ | ↓ |
| Landscape division (2017-2022) | -1E-05 | 1E-05 | 1E+00 | -1E-02 | -6E-04 | -1E-03 |
| | ↓ | ↑ | ↑ | ↓ | ↓ | ↓ |
| Largest Patch Index (2017-2022) | 0.255 | -0.184 | 0.100 | 3.431 | 0.876 | -0.100 |
| | ↑ | ↓ | ↑ | ↑ | ↑ | ↓ |
| Rangeland scale | | | | | | |
| Patch Cohesion Index (2017-2022) | 0.061 | -0.061 | -0.008 | 0.018 | 0.032 | 0.026 |
| | ↑ | ↓ | ↓ | ↑ | ↑ | ↑ |
| Landscape division (2017-2022) | -3E-03 | 3E-03 | 4E-04 | -1E-02 | -3E-05 | -3E-04 |
| | ↓ | ↑ | ↑ | ↓ | ↓ | ↓ |
| Largest Patch Index (2017-2022) | -6.162 | 8.405 | 1.451 | -3.404 | -2.847 | -1.804 |
| | ↓ | ↑ | ↑ | ↓ | ↓ | ↓ |

The Largest Patch Index (LPI) underscores Hammam Biadha's dominance with a value of 3.431, signifying a substantial forest patch, whereas Chouarnia and Sers exhibit low LPI values, indicating fragmentation. In the rangeland scale metrics, patch cohesion values are generally low, suggesting limited connectivity, with Elles showing a negative value indicating poor cohesion. Landscape division values remain close to zero, reflecting a somewhat unified rangeland landscape with varying degrees of fragmentation. Notably, Elles has a high positive LPI (8.405), pointing to a significant rangeland patch, while negative values for Chouarnia and Hammam Biadha indicate fragmentation.

Overall, these findings illustrate Sers as a cohesive forest landscape amidst high fragmentation, Hammam Biadha's notable forest patch alongside fragmented rangeland, and Elles' dominance in rangeland at the cost of forest connectivity, highlighting the diverse conservation and management needs across these regions.

## Semi-natural habitats assessment

Connectivity of fields and semi-natural habitats lies at the very core of supporting agroecology transition in the living lab. These infrastructures are part of semi-natural or, currently referred to, "green infrastructure" or "agroecology infrastructure", which is now recognized as playing a critical role in supporting biodiversity and delivery of ecosystem services underpinning agriculture.

Green infrastructure fosters positive biological interactions that are integral to the design and management of farming systems at the level of the agricultural landscape. This fabric of hedgerows, field margins, woodlands, and water bodies help to realize connectivity and resilience in habitats, supporting great diversity of flora and fauna that further realizes pollination for crops, regulates pests, and contributes to soil health.

This connectivity falls in line with the principles of agroecology through its creation of a network that integrates ecological processes into farming, thereby promoting long-term productivity and less dependence on external inputs.

### From images to knowledge

There is a need to exploit all available data sources to increase the deep understanding of landscape configuration. Photography can fundamentally contribute to this process. Photos are an often-overlooked source of data in ecology, although they have occasionally served as a data source in several research fields in ecology, such as landscape ecology (e.g. to track long-term land cover changes (Depauw et al., 2022).

The aim was to identify different types of agroecological infrastructure in the different units of the ALL from photos collected during Holistic Localized Performance Assessment (HOLPA) Field survey (Figure 17). The respective results are summarized in Figure 18 and Figure 19.

Holistic Localized Performance Assessment (HOLPA) Field survey (a vast data set comprising photos obtained in various geographical locations within the ALL).

**924** photos from the field

Interpretation, identification and categorization of different landscape elements.

**Figure 17.** Method for semi-natural habitats assessment

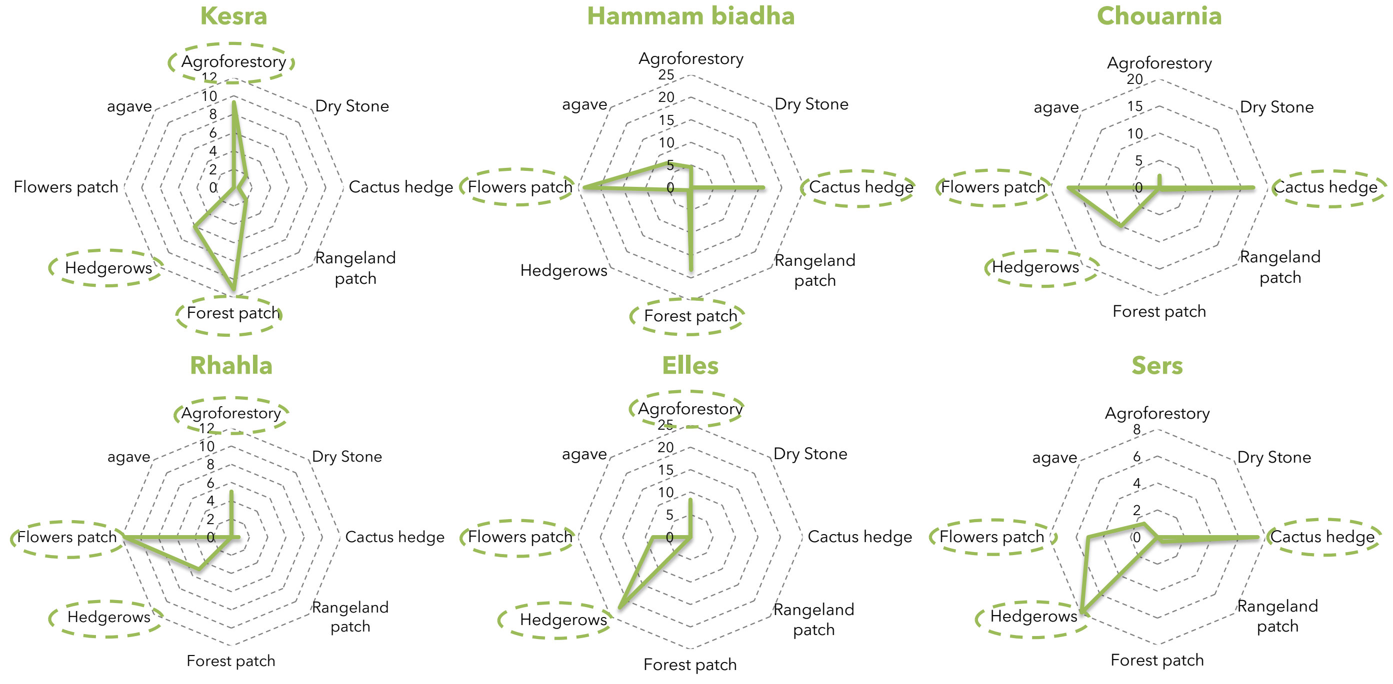


**Figure.18** Share (in%) of agroecological infrastructure per ALL unit

In Kesra, the dominant forest patch featuring Pinus halepensis and Cupressus sempervirens constitutes 11.1% of the area, complemented by agroforestry systems at 9.3% and hedgerows of the same tree species at 6%.

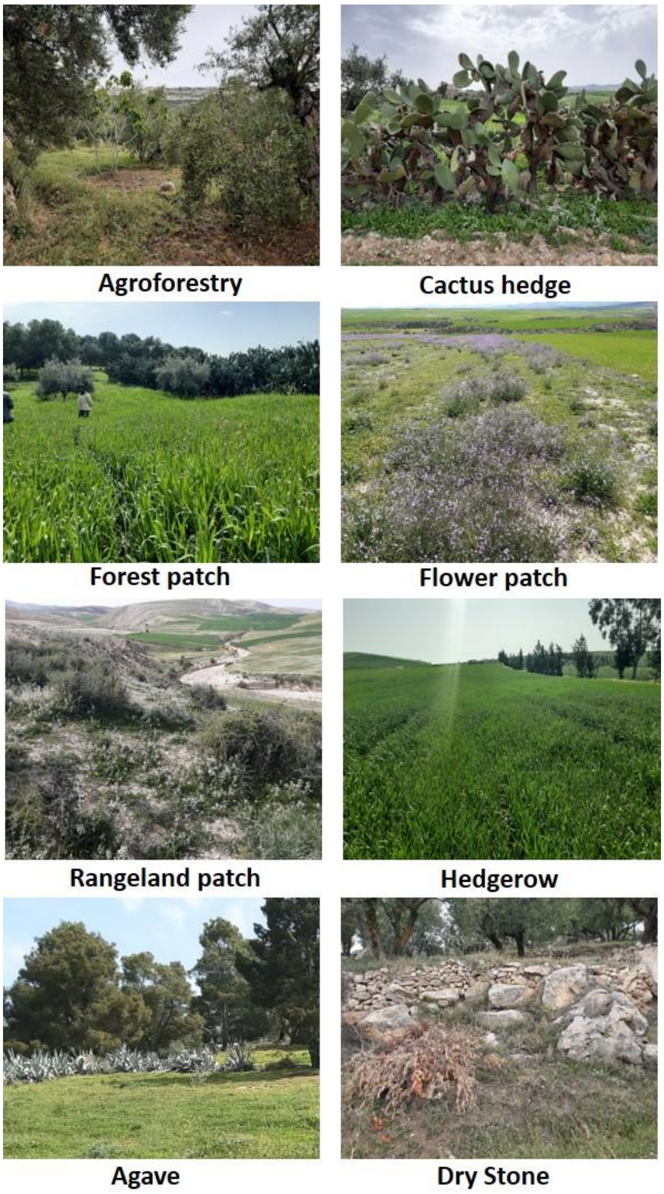

Agroforestry
Cactus hedge
Forest patch
Flower patch
Rangeland patch
Hedgerow
Agave
Dry Stone

**Figure 19.** Examples of used photos (HOLPA Field survey Data)

Hammam Biadha presents a different profile, with flower patches accounting for 23.5%, followed by forest patches of Pinus halepensis at 18.2% and cactus hedges at 15.9%. In Chouarnia, cactus hedges make up 17.2%, alongside flower patches at 16.7% and hedgerows composed of Cupressus sempervirens and eucalyptus at 10%. Rhahla exhibits a similar trend, with flower patches covering 11.7%, agroforestry at 5%, and hedgerows of Cupressus sempervirens and eucalyptus also at 5%. In Elles, the landscape includes hedgerows of Cupressus sempervirens at 11.7%, flower patches at 5%, and agroforestry systems at 5%. Lastly, Sers features hedgerows of Cupressus sempervirens and eucalyptus at 7.9%, cactus hedges at 7.4%, and flower patches at 5.1%. These variations in land cover types illustrate the ecological diversity present in the transect and the significance of different habitat structures in supporting local biodiversity.

# Recommendations for landscape restoration

## Proposal for actions in favor of biodiversity

Forests and rangelands provide a range of services to food production including pollination, pest control, regulation of microclimate (by influencing temperature and water balance), nutritional subsidies for grazing animals, soil nutrient cycling and hydrological services.

**Forest landscape restoration**

This approach aims to regain ecological functionality and strengthen human well-being in deforested, degraded, and fragmentated areas (Mansourian et al. 2005) and focuses on creating of ´multi-functional landscapes (Lamb et al., 2012).

A list of forest landscape restoration practices which can often tailored to ecological and socio-economic context in the Kef-Siliana transect level and ALL level, to enhance biodiversity and improve ecosystem services:

- Agroforestry Systems
- Natural Regeneration
- Reforestation
- Afforestation
- Riparian Buffer Restoration
- Forest Fire Management
- Habitat Connectivity Restoration
- Silvopasture
- Forest Grazing Management

Figure 20 provides the results of an analysis of the change in biomass, expressed in tones of CO2/1ha equivalent (CO2e), following 20 years of various forest restoration approaches, based on the global carbon dioxide removal rates from forest landscape restoration activities method (Bernal et al., 2018) to identify plant species the most adapted to the studied context.

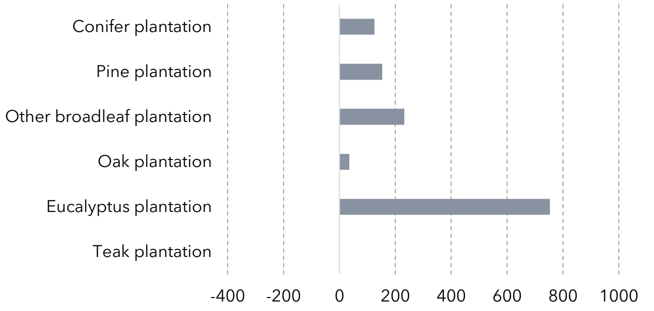


**Figure 20.** Possible change in biomass associated to 20 years of restoration efforts for different plant species

Eucalyptus plantations demonstrated the highest carbon sequestration potential, with a remarkable increase of 753.36 tones CO2e, indicating their effectiveness in accumulating biomass. In contrast, teak plantations showed a minor decrease in biomass, with a change of -0.72 tones CO2e. Oak plantations had a moderate increase of 35.55 tones CO2e, while other broadleaf plantations recorded a more substantial biomass gain of 232.22 tones CO2e. Pine and conifer plantations also contributed positively to biomass accumulation, with increases of 153.25 and 124.97 tones CO2e, respectively. These variations highlight the importance of selecting appropriate species for forest restoration to maximize carbon sequestration and improve ecosystem services.

**Rangeland restoration**

Key methods include reseeding native grasses to restore vegetation cover associated to controlled grazing management the best technic preventing overgrazing and promoting biomass recovery and development. Soil protection measures, such as erosion control structures and planting cover crops, reduce soil erosion and improve water infiltration. Water harvesting techniques, like contour bunding and constructing small check dams, increase water availability in arid ecosystems characterized by the rarity hydric resources (Zerga, 2015).

## Proposal for resilient agricultural practices in favor of biodiversity

Agriculture is both the main factor responsible for biodiversity loss occurring on the farmland areas and the associated declining ecosystem services. However, many sustainable practices can offer a window of innovation and open paths for a sustainable intensification maintaining a positive synergy or a benefic tradeoff for an increasing production while preserving natural resources and restoring landscapes.

The HOLPA Household survey data, which includes responses from 187 households, reflects a clearer vision of the diverse agricultural practices adopted in the ALL (Figure 21).

The survey revealed that a significant majority of farmers engage in monoculture, with 60.8% cultivating annual crops and 27.8% focusing on perennial crops. Agroforestry practices are adopted by only 5.1% of farmers, while the use of cover crops is reported by 1.3%. Crop rotation is relatively more common, with 24.7% of respondents implementing this practice.

Notably, several sustainable and biodiversity-supporting practices, such as establishing hedgerows or live fences, creating home-gardens, mulching, maintaining natural strips or vegetation, and employing pollinator or flower strips, as well as the pull-push method, were not practiced by any respondents. This suggests a limited adoption of agroecological methods, highlighting areas for potential intervention and capacity building to promote more diversified and sustainable farming systems.

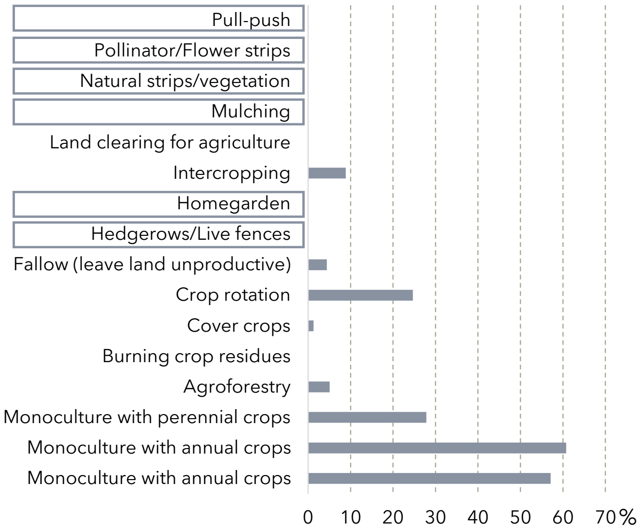


**Figure 21.** Current agricultural practices in the ALL (results from HOLPA field survey)

These below practices can be proposed to enhance biodiversity and make the ALL susceptible to more fauna and flora species:

**Pull-push**

This poly-cropping innovation, integrates practices to manage both insects and soil productivity. Besides, it is a smart technology that capitalizes on natural resources; farmers guaranteed higher yields as well. It consists of intercropping cereals with legumes and planting forage grasses around this intercropping arrangement (Haldorai et al., 2019).

**Pollinator/flower strips**

A strip of flowering plants established in agricultural land can improve pollination services by improving the richness of insect-pollinated plant species (Ouvrard et al., 2018).

**Natural strips or vegetation**

Creating strips of land surrounding the plots can be the barriers of naturally grown grasses and herbs. These strips play an important role on wastewater purification in the soil, slowing water flow and preventing erosion (Haddaway et al., 2018).

**Mulching**

Covering the soil surface can retain soil moisture, reduce soil erosion, and improve soil health (Kader et al., 2017).

**Home garden**

It includes various plant species cultivation characterized by high diversity, (crops, fruits, medicinal plants, and other useful species) (Galluzzi et al., 2010).

**Hedgerows or live fences**

A row of planted trees or shrubs creates natural boundaries. This practice provides habitats and corridors for birds, insects, and small mammals. In addition, this practice connects fragmented habitats enhancing ecological networks, supporting pollinators, controlling soil erosion, enhancing soil fertility and contributing to pest management (Forman & Baudry., 1984).

# Conclusion

The Kef-Siliana transect is characterized by a great diversity of environments and ecosystems and important spot of biological diversity. In the period ranging from 2017 to 2022, significant changes were observed in the distribution of natural areas. However, habitat loss in the transect becomes severe due to numerous synthetic/anthropogenic and natural causes. For instance, while natural habitat area expansion is increasing, the area faces a number of threats including land degradation due to agricultural expansion, overgrazing, deforestation, and frequent fires, which overall, unbalance the ecological system.

Landscape metrics analysis unfortunately shows negative trends, at Kef-Seliana transect level and at the ALL level. This homogenization can have ecological consequences, such as reduced habitat availability, decreased ecosystem services, and lower resilience of the landscape aggravated by the observed limited semi-natural diversity.

Efforts should focus on enhancing and preserving biodiversity through targeted conservation measures and resilient agricultural practices. The suggested restoration guidelines offer concrete examples that support the development of context-relevant and local land use policy in landscape conservation efforts.

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**Zahra Shiri, PhD Research Fellow,** Z.Shiri@cgiar.org

**Quang Bao Le, Agricultural Livelihood Systems Expert,** Q.Le@cgiar.org

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**Zahra Shiri, PhD Research Fellow,** Z.Shiri@cgiar.org

**Quang Bao Le, Agricultural Livelihood Systems Expert,** Q.Le@cgiar.org

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