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## Matrix Land Use Analysis - a Case Study of Landscape Changes in Israeli Carmel Area

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**A STUDY OF LANDSCAPE CHANGES in Israeli Carmel area (Zichron  
Ya'cov site, 1944-1990):  
Application of Matrix Land uses Analysis.**

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Land use and Water Management in a Sustainable Network Society**

***Abstract.**The spatial redistribution of the land uses can be measured by remote sensing conventional methods in the form of the matrices of the land uses redistributions within a given set of regions in a given time period.*

*Two new methods of analysis of such land uses redistribution matrices are proposed. These methods are the applications of the methodology developed in Push-Pull migration analysis (Sonis, 1980) and Key Sector Input-output analysis of economic flows (Sonis et al, 2000) to the land uses transition analysis. The first method represent the geometric and analytical algorithm of decomposition of the land use redistribution matrix into the convex combination of the land use matrices which represents the main tendencies of land use redistributions in a given set of regions in a given time period. Thus, each empirically given land use redistribution can be presented as a superposition of the land uses redistributions connected with the optimal solutions of some extreme land use redistributions corresponding to the parsimonious behavior of land users in a given set of regions in a given time period. The second method represents the construction of the artificial land use landscape corresponding to the minimum information land use redistribution with fixed initial and final land use distributions. The comparison of the empirical land uses landscape with the artificial one represents the spatial specifics of an actual land use redistributions connected with different parsimonious behavior of the land users themselves.*

*As an empirical validation of these new methods the set of 9 different regions in the vicinity of Haifa Carmel area is chosen for different time intervals and the main tendencies of land use redistributions are identified together with their minimum information artificial landscapes.*

*The new methodology and modeling approach will assist future planning in the rural-urban fringe. Optimal solutions for nature conservation and urban development conflicts can be learned through the application of these models.*

**Key Words:** Transition Land use matrix, Superposition Principle; Artificial Land Use Landscapes; Entropy Limitator of homogeneity of land use Distribution.

## 1. Introduction.

Over the last fifty years Mediterranean landscapes have undergone major changes, mainly because of population growth, economic and social changes. The existence of natural, agricultural, and historical landscapes (Naveh and Kutiel, 1990; Prevolototzki *et al.*, 1992; Grossman *et al.*, 1993) is severely endangered due to these processes. Further complication results from a combination of factors: Israel being the focal point of intensive democratic and political changes during the last one hundred years, and its location in the transition zone between the arid and Mediterranean climates.

The Carmel area (including Haifa's periphery) represents a system of varied Mediterranean landscapes, differentiated by soil conditions and vegetation, and by the anthropogenic activities that have taken place over the last hundred years. Accelerated urbanization in addition to agricultural regression corresponding to national and global transformations is the main anthropogenic process influencing the rural system. These processes were conflicted by nature preservation efforts including legislations of reserves and parks. This paper will provide a quantitative description of this conflict evolution during 50 years, 1940-1990.

The objective of this research is to assess rates of landscape transition in general and of vegetation in Mount Carmel region. This course of study is well integrated in attempts to understand process of land use and land-cover changes in regional and global scales (Meyer and Turner, 1994).

The methodology employed here is a combination of multirate air photographs interpretation with analysis of temporal changes using Geographical Information Systems (GIS) and Matrix Land uses Analysis as was developed by M. Sonis in the framework of Matrix Migration Analysis (Sonis, 1980) and Economic Input-Output Analysis (Sonis *et al.*, 2000). The Matrix Land Use Analysis is utilizing the matrices of the land uses redistributions within a given set of regions in a given time period.

This type of analysis includes two new approaches to analysis of land uses redistribution matrices: the superposition principle approach and the minimum information approach.

The first approach represents the geometric and analytical algorithm of decomposition of the land use redistribution matrix into the convex combination of the land use matrices which represents the main tendencies of land use redistributions in a given set of regions in a given time period. Thus, each empirically given land use redistribution can be presented as a superposition of the land uses redistributions connected with the optimal solutions of some extreme land use redistributions corresponding to the parsimonious behavior of land users in a given set of regions in a given time period.

The second approach represents the construction of the artificial land use landscape corresponding to the minimum information land use redistribution with fixed initial and final land use distributions. The comparison of the empirical land uses landscape with the artificial one represents the spatial specifics of an actual land use redistributions connected with different parsimonious behavior of the land users themselves.

As an empirical validation of these new methods from the set of different regions in Israeli Mount Carmel area in the vicinity of Haifa only one typical area of Zicron Ya'acov (the urban settlement within urban-rural fringe of the Carmel Area) will be chosen for different time intervals, 1944-1956, 1956-1970 and 1970-1990, and the main tendencies of land use redistributions will be identified together with their minimum information

artificial landscapes. Other different sub-areas of the Haifa periphery give the similar qualitative picture of the transitions in land uses in urban-rural fringe.

## 2. **Mount Carmel land uses and Zichron Ya'acov research site.**

The Carmel Mountain (area of 240 km square), as defined here is a triangle-shaped mountain. Its apex, in Haifa and its base is along the Yoqne'am - Zikhron Ya'acov road. The area is built from the following major landscape units:

- Urban areas,
- Rural areas combined of both agricultural and built up land uses,
- Vegetation and flora areas,
- Nature reserves and National Parks,
- Forest plantation areas mainly by the KKL.

This research is concerned with mainly the landscape dynamics occurring at the boundaries between these landscape units; in other words, in composite areas representing the major conflicting trends of landscape evolution. The historical dimension is essential for understanding this dynamics in general and vegetation recovery and disturbance in particular. It is important to note for that purpose three major phases: the declaration of the area as Forest Reserve by the British administration Forest Act of 1926, the war of independence (1948) which mark a major decrease in the human disturbance to the natural vegetation due to the abandonment of most of the Palestinian villages, and the legislation of Nature reserve and National Park in 1966 by an Act of the Israeli Knesset (Parliament).

We restrict our consideration by analysis of the land uses transitions in Zichron Ya'acov. Zichron Ya'acov - a Jewish settlement experiencing an advanced process of urbanization. It was established in 1882 (at the beginning of the First Aliya [wave of Jewish immigration]), and until the 1970s the villagers were mostly engaged in the grape-wine growing. In 1990 it had a population of 6,220, but agricultural is no longer the major economic activity. Most of the inhabitants commute to Haifa, where they are employed in various jobs, but some are able to benefit from the emerging local tourist industry.

The Zichron Ya'acov site includes all principal types of anthropogenic activities in the region of Carmel Zone. This enables us to understand the complexity of the landscape processes throughout the Carmel Zone. The changes of landscape that have taken place in Zichron Ya'acov were identified and mapped from air photos taken in 1944, 1956, 1970, and 1990, so that they represent periods of time before the Six Day War, and two dates after it. This war represents a turning point in the processes of land use change and in the economic and social structure of the State of Israel.

## 3. **Research Methodology**

The research methods employed in this study for the construction of empirical data base are based upon the concepts and methodology of GIS, combined with research methods of Historical and Settlement Geography and Ecology.

This study is using quantitative and periodical analyses for gathering the data. In order to employ these means, two preliminary stages were carried out: identifying and mapping the landscape units using air-photos (similar to the work of Gavish and Sonis, 1980); and,

establishing a geographic data base. The principal research stages are described as follows:

### *3.1. Data Gathering.*

Air photographs availability was one of the principal criteria for choosing the research sites, delineating their extents and determining the dates included. The only source of air photographs from the 1940s were those taken by the British Government in 1944-45. This survey provides, in fact, the first full set of air photographs of Israel. The second set of air photographs from 1956 represent the stage of stabilization of settlement activity after the major waves of immigration which entered Israel following the establishment of the State. The air photographs from 1970 were chosen because of their proximity to the period just following the Six Day War when the economy of Israel was reshaped and restructured, and to the time of the steps taken to preserve the Carmel by declaring it a National Park and a Nature Reserve. The last set of air photographs were taken in 1990-1992. Since the various air photographs were taken at flight paths along differing routes, the study area size and its location in relation to the settlements was determined according to the overlap between the flight strips. An area of some 8 sq km was found to represent the average site' size, although the site's outline is considerably amorphic, it basically formed a circle with a diameter of three km. In these areas most of the possible types of landscape units were present. Since the total area of the study comprises some 25 percent of the entire Carmel Zone, our basic assumption is it provides a representative sample of most of the landscape types and their dynamics. This scheme of sites definition is too large extant arbitrary, thus although the size distribution of the different landscape units is informative, the most valuable data concerns rates of landscape change.

The scale of the selected air photographs were between 1:10,000 to 1:20,000. The landscape units were defined according to their interpretability from a mirror stereoscope. The following are the landscape categories that were defined:

1. Heavy and dense vegetation coverage including natural, pine forest, oak woody land and shrubs.
2. Medium vegetation coverage including open forests of oak and pine and scattered shrubs.
3. Light vegetation coverage including bare areas, grassy meadows and isolated trees and shrubs,
4. Orchards, olive groves;
5. Cultivated fields;
6. Recently abandoned fields and terraces. The identification was based upon the identification of abandoned irrigation canals and the existence of randomly scattered sparse bush vegetation;
7. Old abandoned fields, representing the characteristics described in the previous category, but with heavier vegetation cover coexisting with remnants of historical agricultural systems (terraces, canals, etc.)
8. Built-up areas with high and medium building densities, including commercial shopping centers. Functional zones in rural settlements and surrounding urban areas;
9. Sparsely distributed buildings with single houses on the outskirts of urban built-up areas;

The boundaries of the landscape units have been drawn onto a transparency, which were scanned, encoded and georeferenced to form a layer representing the landscape at a single point in time. Combining the layers of the difference dates for each site formed a multi-temporal database.

#### 4. Matrix Land uses Analysis.

##### 4.1. The data used in analysis.

The statistical data for the Matrix Land uses Analysis is presented in the form of matrices of land uses transitions of the following form:

$$M = (p_{ij}) = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1K} \\ p_{21} & p_{22} & \cdots & p_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ p_{K1} & p_{K2} & \cdots & p_{KK} \end{pmatrix} \quad (1)$$

Here the relative land uses transition rates  $p_{ij}$  posses the following properties of the probabilistic vectors:

$$0 \leq p_{ij} \leq 1; \sum_{i,j=1}^K p_{ij} = 1 \quad (2)$$

where  $p_{ij}$  is the relative frequency in percentage of the area changes from landscape category  $I$  to category  $J$  and  $K$  is the landscape area units in given time period.

For example, the table 1 presents the matrix of landscape transition rates in the area of Zichron Ya'acov, in three time periods 1944-1956, 1956-1970, 1970-1990.

The row sums  $S_{i\bullet}$  of the elements standing in rows are giving the initial distribution of land uses ratios ( $ID$ ) in the beginning of the time period. The column sums  $S_{\bullet j}$  of the elements standing in columns are giving the final distribution of land uses ratios ( $FD$ ) in the end of the time period

$$\begin{aligned} ID : S_{i\bullet} &= \sum_{j=1}^K p_{ij}, \quad i = 1, 2, \dots, K \\ FD : S_{\bullet j} &= \sum_{i=1}^K p_{ij}, \quad j = 1, 2, \dots, K \end{aligned} \quad (3)$$

It is obvious that the vectors  $ID$  and  $FD$  of initial and final distributions are probabilistic vectors.

1944-1956

	1	2	3	4	5	6	7	8	9	ID: $S_{i\bullet}$
1	4.3	3.5	0.8	0	0	0	0	0	0.9	9.5
2	2.1	15.4	0	0	0	0	0	0	2.3	19.8
3	1.8	6.6	14.2	1.3	2.6	0	0	1.3	1.5	29.3
4	0	1.1	0.6	5.6	1.1	0	0	0	0.5	8.9
5	0.3	2.1	5.8	2.8	11.8	1.6	0	0	0.8	25.2
6	0	0	0.8	0	0	0	0	0	0	0.8
7	0	0	1.5	0.5	0	0	0	0	0.6	2.6
8	0	0	0	0	0	0	0	3.5	0	3.5
9	0	0	0	0	0	0	0	0	0.4	0.4
<i>FD: <math>S_{\bullet j}</math></i>	8.5	28.7	23.7	10.2	15.5	1.6	0	4.8	7	100

1956-1970

	1	2	3	4	5	6	7	8	9	ID: $S_{i\bullet}$
1	4.5	2.5	0.3	0	0	0	0	0.2	0.1	7.6
2	8.7	12.6	1.6	0.9	0.4	0	0	1.4	0.1	25.7
3	1.8	6.4	13.9	0.2	0.5	0	0	0.9	1	24.7
4	0.2	0.7	1.4	5.3	2.7	0	0	0.2	0.4	10.9
5	0.8	1	2.9	4.7	6.5	0	0	0.4	0.5	16.8
6	0	0	2.3	0.4	0	0	0	0.3	0	3
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	4.7	0	4.7
9	0	0	0.2	0	0	0	0	2.4	4	6.6
<i>FS: <math>S_{\bullet j}</math></i>	16	23.2	22.6	11.5	10.1	0	0	10.5	6.1	100

1970-1990

	1	2	3	4	5	6	7	8	9	IS: $S_{i\bullet}$
1	10.5	3.3	0	0	0.4	0	0	2.7	0.5	17.4
2	10.2	7.1	2.1	0.3	0.4	0	0	5.1	0.1	25.3
3	0.7	7	8.4	1.1	0.7	0	0	4	0.5	22.4
4	0.5	1.5	0.4	3.8	3.8	0	0	1.6	0.4	12
5	0.2	0.7	0.7	1.3	5.1	0	0	0.4	1.2	9.6
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	10.1	0	10.1

	9	0.4	0	0	0	0	0	0	2.1	0.7	3.2
FS: $S_{\bullet j}$		22.5	19.6	11.6	6.5	10.4	0	0	26	3.4	100

Table 1. Matrices of landscape transition rates in the area of Zichron Ya'acov, 1944-1990

#### 4.2. Temporal Dynamics of Initial and Final distributions of relative shares of actual land uses.

For the purposes of representation of the temporal changes in land uses shares we will use the ranking of the shares according of their size

The Rank-Size sequences of land uses distributions in the three time periods are presented in the following table 2.

1944-1956		1956-1970		1970-1990	
Initial Distr.	Final Distr.	Initial Distr.	Final Distr.	Initial Distr.	Final Distr.
3   29.3	2   28.7	2   25.7	2   23.2	2   25.3	8   26
5   25.2	3   23.7	3   24.7	3   22.6	3   22.4	1   22.5
2   19.8	5   15.5	5   16.8	1   16	1   17.4	2   19.6
1   9.5	4   10.2	4   10.9	4   11.5	4   12	3   11.6
4   8.9	1   8.5	1   7.6	8   10.5	8   10.1	5   10.4
8   3.5	9   7	9   6.6	5   10.1	5   9.6	4   6.5
7   2.6	8   4.8	8   4.7	9   6.1	9   3.2	9   3.4
6   0.8	6   1.6	6   3	6   0	6   0	6   0
9   0.4	7   0	7   0	7   0	7   0	7   0

Table 2. The rank-size sequences of Initial and Final land uses distributions in Zichron Ya'acov area, 1944-1956, 1956-1970, 1970-1990.

It is possible to see that land uses shares in the end of a time period do not coincide quantitatively with the shares in the beginning of the next time period. This can be explained by that the air photographs in each period are not identical by scale and by angle of view and, therefore, the practical measurement the land uses shares give the measurement deviations which in our case for all the time periods do not exceed 3%. Nevertheless the Rank-Size sequences are coinciding qualitatively, i.e. the ranking of land uses are the same in the end of each time period and in the beginning of the next one. This fact supports significantly the robustness of our method of measurement of land uses.

The dynamics of redistributions of land uses shares reveals the following tendencies of change:

- The light vegetation coverage (3) loses its magnitude (from 29% to 12%) descending from the first place in ranking in 1944 period to the fourth place in 1990;
- The medium vegetation coverage (2) occupies in 1944 and in 1990 about the same size (about 20%) and taking the first place in ranking from the 1956 till 1970 (covering about 25%);
- The heavy and dense vegetation (1) climbs up from fourth-fifth place in 1944. 1956 (about 9%) to the second place in ranking in 1990 (about 22%);
- The orchards and olive plantations (4) stays in all time periods on the fourth-fifth place (loses its magnitude from about 10% to 6%);
- The cultivated fields (5) descend from the second place in 1944 (about 25%)



- to the fifth place in 1990 (about 10%);
- The abandoned fields (6,7) which occupies about 3% in 1944 disappears in 1970;
- The dense built-up areas (8) are growing strongly from the six, seventh place in 1944-56 (about 5%) to the first place in ranking in 1990 (about 25%);
- The sparse urban built-up areas (9) which reached six place in 1956 (7%) stands in the end of ranking in 1990 with 3%.

The land uses distribution dynamics became much more visible on the aggregated level of only three aggregated land uses types: I. Vegetation (1, 2, 3); II. Agricultural uses (4, 5, 6, 7) and III. Build up areas (8, 9) (see table 3):

	1944	1956	1970	1990
I	58.6	59.5	63.5	53.7
II	37.5	29	21.6	16.9
III	3.9	11.5	14.9	29.4

Table 3. Temporal changes in aggregated average land uses shares, Zichron Ya'acov (%)

This table shows that the main aggregated average tendencies in land uses redistribution are:

- The Vegetation (I) is covering about 60% of Zichron Ya'acov area;
- The Agriculture uses (II) gradually decrease from 40% to 20%;
- The Build up area (III) is strongly increases from 4% to 30%.

The fact that most of the sites present similar trends despite variations in their land uses composition is important from two points of view: firstly it is strengthening the significance of the trends, and secondly, it suggests that the sites respond in a similar way to the forces deriving the landscape change.

#### 4.3. Sum Products Matrix (SPM) and Artificial land uses transition landscape.

This subchapter presents the methodology of matrix analysis first developed in the Key Sector Input-Output analysis of economic flows (Sonis *et al*, 2000).

Land uses transition matrices  $M$  (3, 4) and their row and column sums  $S_{i\bullet}, S_{\bullet j}$  (5) can be used for the calculation of Sum Products Matrices (SPM):

$$S = (S_{\bullet i}, S_{j\bullet}) = \begin{pmatrix} S_{1\bullet} \\ S_{2\bullet} \\ \vdots \\ S_{n\bullet} \end{pmatrix} (S_{\bullet 1}, S_{\bullet 2}, \dots, S_{\bullet n}) \quad (= (s_{ij})) \quad (4)$$

It is important to underline that the column and row multipliers of the SPM are the same as those of the Land uses transaction matrix  $M$ .

The *sum product matrix* (SPM) provides a visual representation (*artificial landscape*) of the structure of land uses, giving a basis for the comparison of structures of different land uses transitions in the same area over time.

The definition (4) defines a specific *cross structure* of the SPM which will be presented below. First of all, the largest component of the SPM is the product of the largest column and row sums:

$$\max_{ij} s_{ij} = (\max_i S_{i\bullet}) (\max_j S_{\bullet j}) = S_{i_l\bullet} \cdot S_{\bullet j_l} \quad (5)$$

Moreover, all rows of the SPM are proportional to the row of column sums and the  $i_l$ th row, corresponding to the largest row sum  $S_{i_l\bullet}$ , is the “biggest” row with the maximal components in each column.

Analogously, all columns of the SPM are proportional to the column of the row sums and the  $j_l$ th column, corresponding to the largest column sum  $S_{\bullet j_l}$ , is the “largest” column with maximal components in each row.

These proportionality properties imply that the largest components of the SPM are included in the cross  $\mathfrak{C}_{i_l, j_l}$  (generated by the  $i_l$ th row and  $j_l$ th column in such a way that for each column (row) of the SPM the largest element lies in the  $i_l$ th row ( $j_l$ th column)). The largest component of the SPM is located in the center of this cross. Furthermore, if the cross  $\mathfrak{C}_{i_l, j_l}$  is excluded from the SPM, then the next cross  $\mathfrak{C}_{i_{II}, j_{II}}$  will include the largest remaining elements; the same property holds for the succeeding crosses  $\mathfrak{C}_{i_{III}, j_{III}}, \mathfrak{C}_{i_{IV}, j_{IV}}, \dots, \mathfrak{C}_{i_N, j_N}$ .

This cross-structure of the SPM is essential for the visualization of the land uses transitions structure with the help of *artificial structural landscapes*. Essentially, SPM is presented as a three-dimensional picture of the land uses transitions; by corresponding manipulation of the row and column ordering, it is possible to directly compare the land uses transitions structure of several areas in different time periods.

For the construction of these landscapes one can reorganize the location of rows and columns of the SPM in such a way that the descending sequence of the centers of crosses appears on the main diagonal.

This rearrangement also reveals the descending rank-size hierarchies of row and column sums. Moreover, we can consider the rank-size sequences of the components of the SPM and to replace the entries with their ranks. On the basis of the rearranged SPM, the three-dimensional diagram of descending *economic landscape* can be drawn, where the two-dimensional plane represents the hierarchy of column and row sums, and the third dimension - the height of the bars - represents the volume of products of column and row sums.

It is important to stress that the construction of artificial landscapes for different regions, or for the same region at different time periods, creates the possibility for the establishment of taxonomy of the land uses transitions on the basis of visual representation of the similarities and differences in the structure of transitions.

4.4. Maximum Entropy property of SPM.

Consider all land uses transition matrices,  $N = (r_{ij})$  with the property that the row and column sums are equal to the row and column sums of the concrete land uses transition matrix  $M = (p_{ij})$ :

$$\sum_j r_{ij} = \sum_j p_{ij} = S_{i\bullet}, \quad \sum_i r_{ij} = \sum_i p_{ij} = S_{\bullet j} \quad (6)$$

We can attribute to each positive matrix  $N$  the Shannon entropy

$$EntN = -\sum_{i,j} r_{ij} \log r_{ij} \quad (7)$$

(Here we apply the usual assumption  $0 \log 0 = 0$  )

**The maximum entropy theorem.** The sum product matrix  $S$  has a maximum entropy property (Sonis, 1968. 1996):

$$EntN = -\sum_{i,j} r_{ij} \log r_{ij} \leq -\sum_{i,j} S_{i\bullet} S_{\bullet j} \log S_{i\bullet} S_{\bullet j} = EntS = E_{\max} \quad (8)$$

The proof of this statement it possible obtains by direct calculation from the well-known Shannon information inequality (Shannon and Weaver, 1964, p. 51).

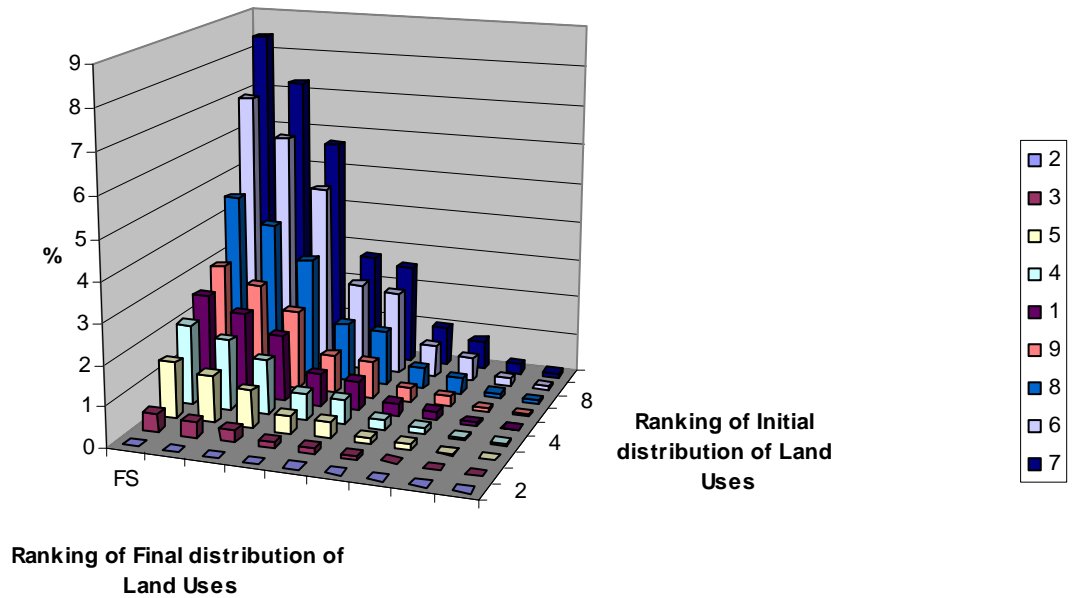
The SPM matrix  $S$  may be considered to present *the most homogeneous* distribution of the components of the column and row sums of the land uses shares  $M$  . Thus, while the SPM does not take into account the specifics of the land uses transformations, it does provide the aggregate representation of land uses *equalization tendencies* in the spatial interactions between land uses. To underline this, let us note that if the land uses transitions matrix  $M$  has equal column and row sums, then the artificial land uses landscape will be a flat, horizontal plane.

Land Uses	7	6	8	9	1	4	5	3	2ID	
3	0	0.47	1.41	2.05	2.49	2.99	4.54	6.94	8.41	29.3
5	0	0.4	1.21	1.76	2.14	2.57	3.91	5.97	7.23	25.2
2	0	0.32	0.95	1.39	1.68	2.02	3.07	4.69	5.68	19.8
1	0	0.15	0.46	0.67	0.81	0.97	1.47	2.25	2.73	9.5
4	0	0.14	0.43	0.62	0.76	0.91	1.38	2.11	2.55	8.9
8	0	0.06	0.17	0.25	0.3	0.36	0.54	0.83	1	3.5
7	0	0.04	0.12	0.18	0.22	0.27	0.4	0.62	0.75	2.6
6	0	0.01	0.04	0.06	0.07	0.08	0.12	0.19	0.23	0.8
9	0	0.01	0.02	0.03	0.03	0.04	0.06	0.09	0.11	0.4
FD	0	1.6	4.8	7	8.5	10.2	15.5	23.7	28.7	

Table 4. The Rank-Size hierarchies of row and column sums and corresponding maximum entropy SPM matrix, for Zichron Ya'acov area, 1944-56.

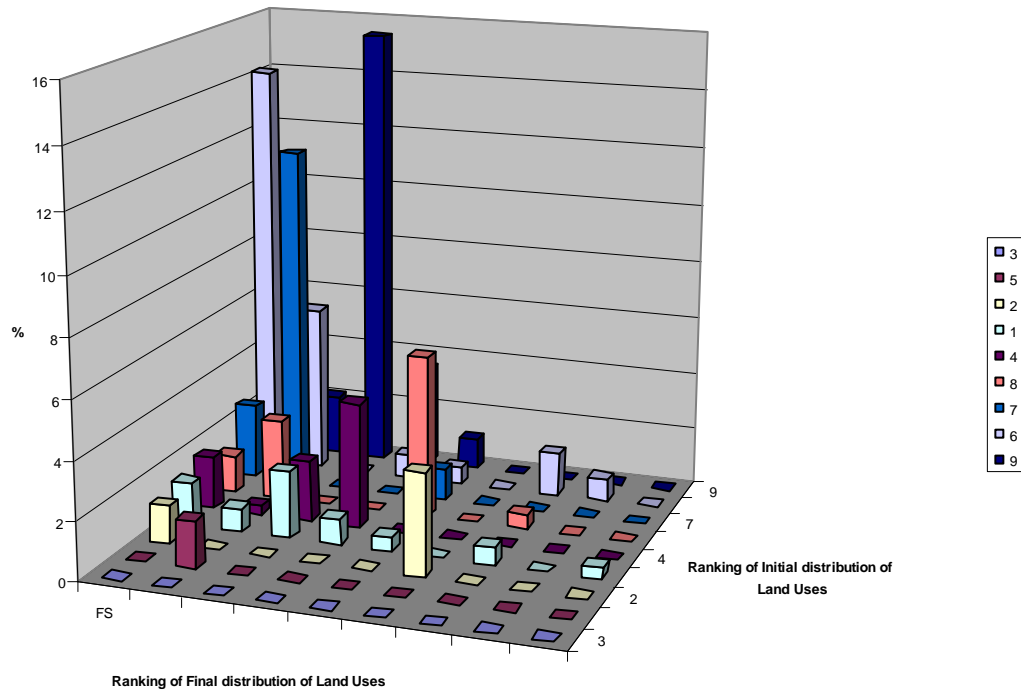
The table 4 presents the Rank-Size hierarchies of row and column sums of the land uses transitions matrix for Zichron Ya'acov area and corresponding to maximum entropy SPM. This matrix is calculated with the help of formulae (4) on the basis of land uses transition matrix from table 1. The corresponding cross-structure interpreted graphically in figure 1. In this figure, the order of the rows provides the hierarchy of rows in initial distribution of land uses while the order for the columns provides a similar structure for the column sums in final distribution of land uses. The land uses are arranged in such a way that the northwest quadrant provides the highest elevation and the *artificial land uses transitions landscape* slopes towards the east and south. At the apex of the hierarchy is the intersection of land uses 3 (Light vegetation coverage) and 2 (Medium vegetation coverage).

**Figure 1. Maximum Entropy Artificial Land Uses landscape, Zichron Ya'acov, 1944-56**



For comparison the figure 2 presents the actual land uses landscape based on the same rank-size hierarchy.

**Figure 2. Rank-Size of actual Land Uses transitions Landscape, Zichron Ya'acov, 1944-56**



This landscape of actual land uses transitions presents the actual preferences in choice of land uses in Zichron Ya'acov area; 1944-56 in comparison with maximum homogeneity of land uses transition shares presented by SPM. These preferences can be reevaluated by calculating the difference

*M-S*

(9)

	7	6	8	9	1	4	5	3	2
3	0	-0.5	-0.1	-0.6	-0.7	-1.6	-1.9	7.2	-1.8
5	0	1.2	-1.2	-1	-1.8	0.2	7.9	-0.2	-5.1
2	0	-0.3	-1	1	0.4	-2	-3.1	-4.7	9.7
1	0	-0.2	-0.5	0.2	3.6	-1	-1.5	-1.5	0.8
4	0	-0.1	-0.4	-0.1	-0.8	4.7	-0.3	-1.5	-1.5
8	0	-0.1	3.3	-0.2	-0.3	-0.4	-0.5	-0.8	-1
7	0	0	-0.1	0.4	-0.2	0.2	-0.4	0.9	-0.7
6	0	0	0	-0.1	-0.1	-0.1	-0.1	0.6	-0.2
9	0	0	0	0.4	0	0	-0.1	-0.1	-0.1

*Table 5. Difference of the matrices M-S (shaded numbers present the preferable land uses.)*

The table 5 reveals that preferable land uses in Zichron Ya'acov area during 1944-56 were 1, 2, 3 (Vegetation coverage), 4 (Orchard and olives plantation) and 5 (cultivated fields). In the period 1956-70 the land uses preferences were 1, 2, 3 (Vegetation coverage), 5 (Cultivated fields) and new land use 9 (Sparse build up area).

In the period 1970-90 the land uses preferences were 1, 2, 3 (Vegetation coverage), 5 (Cultivated fields) and a land use 9 (Sparse build up area) was exchanges by land use 8 (Dense build up area).

It is important to note that for periods 1956-1970 and 1970-1990 the artificial land uses landscapes became more flat.

#### 4.5. Limitators of homogeneity of land uses coverage.

The deviation of actual land uses transitions from the most homogeneous land uses transitions can be measured by the limitator of homogeneity first introduced by the Russian geographer B. L. Gurevich (Gurevich, 1968; see also Sonis, 1968):

$$L = 1 - \frac{EntM}{E_{max}} \quad (10)$$

If the entropy  $EntM$  obtains the maximum value  $E_{max}$ , in the case of maximal homogeneity of land uses transition shares, then the limitation of this homogeneity does not exist, i.e.,  $L = 0$ . In the case of the maximal heterogeneity, when the matrix  $M$  of land uses transition include only one non-zero component 1, then  $EntM = 0$  and  $L = 1$  and we have the case of maximal limitation of homogeneity.

Table 6 presents the values of the limitator of homogeneity of land uses in three time periods.

	ENT M	E <sub>max</sub>	L
1944-1956	1.27	1.55	0.18
1956-1970	1.32	1.61	0.19
1970-1990	1.32	1.56	0.15

Table 6. Entropy and limitator of land uses homogeneity measures for Zichron YA'acob area in 1944-1956-1970-1990.

For all time periods the values of the limitator of homogeneity of land uses covering are changing between 15-19 %, which mean that the limitations of homogeneity of land uses transitions is low and dynamics of land uses transitions is slow.

#### 5. Decomposition and assemblage of the land uses sub-areas

The land uses transformations in the given area during some time interval can be considered from the view-point of the decomposition and view-point of assemblage. The decomposition means the division of the sub-area under some definite land use in the beginning of time interval into the set of sub-areas under different land uses in the end of the time interval; the assemblage means the bringing together all sub-areas under the same land use in the end of time interval into the unified area under the only one type of land uses.

This section deals with an analysis and spatial representation of decomposition and assemblage in a real land uses transformations. We restrict ourselves to a detailed representation of the analysis of decomposition, since the scheme of assemblage analysis can be considered analogously.

##### 5.1. The convex polyhedron of the admissible land use transformations

Let us consider the land uses transformations on  $K$  different types of land uses in a given geographical areas in a given time interval. These transformations can be statistically described by the transformation matrix (3, 4):

An initial land uses distribution for decomposition analysis is:

$$S_{i\bullet} = \sum_{j=1}^K p_{ij}, \quad i = 1, 2, \dots, K \quad (11)$$

These data allows for the incorporation of the actual state of the land uses system,  $M$ , into the polyhedron of admissible states. For the decomposition analysis, the convex polyhedron of admissible states includes the transition matrices  $X = [x_{ij}]$ , satisfying the following system of linear constraints:

$$\begin{cases} x_{ij} \geq 0, & i, j = 1, 2, \dots, n \\ \sum_{i,j=1}^K x_{ij} = 1 \\ \sum_{j=1}^K x_{ij} = S_{i\bullet}, & i = 1, 2, \dots, K \end{cases} \quad (12)$$

### 5.2. Normalized unite cube of admissible land uses transition.

The description of the polyhedron of admissible land uses transitions (12) can be simplified by compressing them into a many-dimensional unit cube of stochastic matrices

$R = [r_{ij}] = [x_{ij} / S_{i\bullet}]$  for decomposition analysis:

$$\begin{cases} r_{ij} \geq 0, & i, j = 1, 2, \dots, n \\ \sum_{i=1}^n r_{ij} = 1, & j = 1, 2, \dots, n \end{cases} \quad (13)$$

The correspondence between the matrices  $X$  of admissible transition matrices from the polyhedron (12) and the stochastic matrices  $R$  from the normalized polyhedron (13) is one to one; transfer from matrix  $R$  to  $X$  is easily done by multiplication of rows of the matrix  $R$  on the sums  $S_{i\bullet}$ . The unit cube (13) of the stochastic matrices is generated by the vertices  $V$ , which are 0-1 stochastic matrices with only one non-zero component 1 in each row. The matrix  $M = [p_{ij}]$  of an actual land uses transitions converted into the stochastic matrix  $R_0 = [p_{ij} / S_{i\bullet}]$  within the unit cube (13) of all stochastic matrices; thus, the procedure of the decomposition can be applied for analysis of a normalized transition matrix. Moreover, because of the 0-1 structure of the vertices  $V$ , each vertex-matrix  $V$  presents the extreme tendency of transfer of land uses only to the one type of land use. Thus the vertices of normalized unit cube are defined by the rule: “everything or nothing” – each row of the vertex-matrix  $R$  includes only one non-zero coordinate.

### 5.3. Superposition principle, definition of the main tendencies in land use transitions and their degrees of realization in real land uses.

The superposition approach decomposes the actual land uses transition matrix  $R_1$  into the weighted sum of matrices,  $V_k$  representing the action of the extreme transition tendencies:

$$R_0 = p_1 V_1 + p_2 V_2 + \dots + p_m V_m \quad (14)$$

where  $1 \geq p_s \geq 0$  and  $p_1 + p_2 + \dots + p_m = 1$ .





This matrix is calculated by dividing the rows of the matrix  $M$  on the row sums  $S_{i\cdot}$ . The shaded coefficients of this stochastic matrix represent the maximal elements of each row. The 0-1 stochastic matrix  $V_1$ , which presents the main tendency in the land uses transitions, obtains the following form:

$V_1$		1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	0
7	0	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0
9	0	0	0	0	0	0	0	0	0	1

This stochastic 0-1 matrix is obtained from matrix by putting 1 instead each shaded coefficient. The compressed form of this matrix presents the main tendency of land uses transition:

$V_1$	
1	1
2	2
3	3
4	4
5	5
6	3
7	3
8	8
9	9

$V_1$  represents the main tendency of preservation of the following land uses: Vegetation coverage (1,2,3), preservation of Agricultural uses (4,5), preservation of Build up areas and transfer of Abandoned fields (6,7) to Sparse vegetation coverage (3).

The weight of this tendency is 0.45 (this value presents the minimum from the set of all shaded coefficients in matrix  $R_0$  and also defined the first "bottleneck" problem: the interdiction to the preservation of Sparse vegetation coverage (3)).

The following decomposition holds:

$$R_0 = 0.45V_1 + 0.55R_1 \tag{15}$$

where  $R_1$  is the first remainder. The equation (15) implies that

$$R_1 = 1.8182R_0 - 0.8182V_1 \tag{16}$$

Therefore, this remainder has a form:



The decomposition of the second remainder  $R_2$  has a form:

$$R_2 = 0.23V_3 + 0.77R_3 \quad (20)$$

with the third extreme tendency

$V_3$	
1	2
2	2
3	5
4	2
5	2
6	3
7	4
8	8
9	9

which includes the "bottleneck" in transition from Agricultural uses (5) to Medium (2) vegetation coverage. The substitution of (20) into (19) gives the decomposition of normalized land uses transition  $R_0$  :

$$R_0 = 0.45V_1 + 0.18V_2 + 0.09V_3 + 0.28R_3 \quad (21)$$

This decomposition includes three extreme tendencies  $V_1, V_2, V_3$  with aggregated weight 0.72. The analysis of sequential remainder  $R_3 = 0.22V_4 + 0.78R_4$

$R_3$	1	2	3	4	5	6	7	8	9
1	0	0.36	0.31	0	0	0	0	0	0.33
2	0.37	0.22	0	0	0	0	0	0	0.41
3	0.22	0.15	0.12	0.16	0.01	0	0	0.16	0.18
4	0	0.14	0.24	0	0.43	0	0	0	0.2
5	0.04	0	0.17	0.39	0.06	0.22	0	0	0.11
6	0	0	1	0	0	0	0	0	0
7	0	0	0.45	0.38	0	0	0	0	0.17
8	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	1

gives the following superposition of four extreme tendencies with the aggregated weight 0.78:

$$R_0 = 0.45V_1 + 0.18V_2 + 0.09V_3 + 0.06V_4 + 0.22R_4 \quad (22)$$

where fourth extreme tendency:



	X		X		X		X		X
8	8	8	8	8	8	8	8	8	8
9	9	9	8	9	8	9	1	9	8

In the period 1970-1990 the Recent and Old abandoned fields (6 and 7) disappeared. The extreme tendency  $V_3$  represents the strong urbanization build up process in this decade.

7. *The assemblage analysis of land uses transitions in Zichron Ya'acov site.*

Analogously to the analysis of decomposition of land uses coverage, we will consider first the main tendencies of assemblage of land uses transitions in Zichron Ya'acov area during 1944-1956. (cf. subchapter 6). The land uses transition is described by the matrix

$M$	1	2	3	4	5	6	7	8	9
1	4.3	3.5	0.8	0	0	0	0	0	0.9
2	2.1	15.4	0	0	0	0	0	0	2.3
3	1.8	6.6	14.2	1.3	2.6	0	0	1.3	1.5
4	0	1.1	0.6	5.6	1.1	0	0	0	0.5
5	0.3	2.1	5.8	2.8	11.8	1.6	0	0	0.8
6	0	0	0.8	0	0	0	0	0	0
7	0	0	1.5	0.5	0	0	0	0	0.6
8	0	0	0	0	0	0	0	3.5	0
9	0	0	0	0	0	0	0	0	0.4
$S_{\cdot j}$	8.5	28.7	23.7	10.2	15.5	1.6	0	4.8	7

With the following final distribution of shares of different land uses in the end of 1956:

$S_{\cdot j}$	8.5	28.7	23.7	10.2	15.5	1.6	0	4.8	7
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The normalized markovian matrix  $Q_0$ , corresponding to the land uses transition matrix  $M$  has a form (in markovian matrix the column sums of coefficients always equal to 1):

$Q_0$	1	2	3	4	5	6	7	8	9
1	0.51	0.12	0.03	0	0	0	0	0	0.13
2	0.25	0.54	0	0	0	0	0	0	0.33
3	0.21	0.23	0.60	0.13	0.17	0	0	0.27	0.21
4	0	0.04	0.03	0.55	0.07	0	0	0	0.07
5	0.03	0.07	0.24	0.28	0.76	1	0	0	0.11
6	0	0	0.03	0	0	0	0	0	0
7	0	0	0.07	0.04	0	0	0	0	0.09
8	0	0	0	0	0	0	0	0.73	0
9	0	0	0	0	0	0	0	0	0.06

Analogously to (22) the following superposition of four extreme tendencies of the assemblage process with the aggregated weight 0.77 can be derived:

$$Q_0 = 0.32W_1 + 0.21W_2 + 0.13W_3 + 0.11W_4 + 0.23Q_5$$

where

$W_1$	1	2	3	4	5	6	7	8	9
	1	2	3	4	5	5XXXX		8	2
$W_2$	1	2	3	4	5	6	7	8	9
	2	2	3	5	5	5XXXX		8	3
$W_3$	1	2	3	4	5	6	7	8	9
	3	3	5	4	5	5XXXX		3	1
$W_4$	1	2	3	4	5	6	7	8	9
	1	1	5	3	3	5XXXX		8	5

The first extreme tendency  $W_1$  presents the fact that almost all (1-8) land uses types are the biggest supplies of coverage to themselves; only the Sparse urban areas coverage (9) is supported by transition from Medium Vegetation coverage area (2) and this transition contains the "bottleneck". The weight this first tendency is 0.32. It is interesting to note that on the level of aggregated land uses of the types I, II, III other tendencies are similar with "bottlenecks" interdicting the transition to the same Sparse build up area (9).

For time period 1956-1970 the decomposition of the assemblage process is:

$$Q_0 = 0.45W_1 + 0.16W_2 + 0.11W_3 + 0.08W_4 + 0.19Q_5$$

with four extreme tendencies of assemblage (with the aggregated weight 0.81):

$W_1$	1	2	3	4	5	6	7	8	9
	2	2	3	4	5XXXX	XXXXX		8	9
$W_2$	1	2	3	4	5	6	7	8	9
	1	3	3	5	4XXXX	XXXXX		9	9
$W_3$	1	2	3	4	5	6	7	8	9
	1	3	5	5	5XXXX	XXXXX		2	3
$W_4$	1	2	3	4	5	6	7	8	9
	3	1	6	5	4XXXX	XXXXX		3	5

For time period 1970-1990 the decomposition of the assemblage process is:

$$Q_0 = 0.35W_1 + 0.16W_2 + 0.14W_3 + 0.10W_4 + 0.25Q_5$$

With four extreme tendencies of assemblage (with the aggregated weight 0.75):

$W_1$	1	2	3	4	5	6	7	8	9
	1	2	3	4	5XXXX	XXXXX		8	5
$W_2$	1	2	3	4	5	6	7	8	9
	2	3	3	4	5XXXX	XXXXX		3	9
$W_3$	1	2	3	4	5	6	7	8	9

	2	3	3	5	5	XXXX	XXXX	2	3
$W_4$	1	2	3	4	5	6	7	8	9
	2	1	2	3	5	XXXX	XXXX	1	1

These extreme tendencies present the continuation of self-support of land uses coverage together with the enlargement of the Build up areas, which contains all "bottleneck problems" interdicting the assemblage of Urban land uses (8, 9).

## 8. Discussion

In this paper we consider a dynamics of land uses transition shares of nine groups of categories of land uses coverage and their aggregation into three major types: agricultural areas, areas with natural vegetation and build up areas.

The purpose of the paper is methodological: to present in detail the Matrix land use analysis and discuss shortly the case of the Mount Carmel urban-rural fringe.

### 8.1. Transitions in the agricultural areas

Historical records of The British government land use survey (village statistic, 1945) reveal that agricultural land uses cover a major part of the Mount Carmel region of 1940's. In broad terms, the villages' land uses were composed of 0.25% build up areas, 10% of orchards and almost 90% of cultivated fields. Most of the open areas beyond the villages' boundaries were grazing areas. According to a survey of the natural pasture of Israel which was conducted in 1956 a total of 140,000 dunams had been used for grazing at different intensities. Although these figures represent significant phase of change since 1948, it indicate together with the data of fields and orchards that the absolute majority of the area was used for agriculture. At the beginning of the 1990's the picture as represented in the research sites is totally different : cultivated fields and orchards have been reduced to less than 25% while the built-up areas were expanded and became a dominant land use in most of the sites. It is important to note, that the mountain agriculture was almost completely abandoned or decreased radically while cultivated fields and orchards were less affected in the valleys as it is represented in Zicron Ya'acov.

In broad terms, this land transformation can be divided into two phases: at the first phase the rate of decreasing agriculture is higher than that of increasing built-up area, while inverse relationships exist in the second phase. The replacement of agricultural land by built-up areas is well known around the world in general and in Mediterranean countries in particular (see for example Frandez Ales *et al.*, 1992 and Barbero *et al.*, 1990). However, a distinction must be made between endogenic processes of built-up area growth onto agricultural lands taking place in core rural areas in general and in the Carmel in particular, and exogenic processes where agriculture land is lost due to the expansion of urban areas into the rural zone as is the case in the periphery of the Tel Aviv Metropolitan Zone and Haifa (Gavish and Sonis, 1979; Amiran 1996).

Socio-economic changes following population growth are the main deriving forces for this land transformation. A comparison between rates of built-up area increase and those

of population growth shows that the first is of much higher magnitude than the second. Part of the explanation for the lack of correspondence between the growth rates of the population and the built-up areas stems from the irregular pattern of the settlement and the traditional form of its land tenure system. One can identify here simultaneous processes of discontinuous expansion and infilling of gaps (Sofer and Kipnis, 1980). By a process of discontinuous expansion, houses and neighborhoods are established in agricultural areas outside the settlement's boundaries according to the land ownership system, and then by infilling, houses are built on the land between the periphery and the old borders. Both these processes take place at the same time on different sectors of the rural area. The overall settlement density is reduced on one hand and there is a need for excess development of infrastructure (per housing unit) on the other. The transformation of rural areas to urban brings about the total loss of traditional sources of income, results in a change in life-style, and, eventually, in the disappearance of the culture associated with the former way of life.

### *8.2. Transition trends in open areas*

The general picture of changes in these areas is the increase in vegetation density of as a result of the forced reduction of grazing pressures and woodcutting. Mainly because of the enforcement of the legislation of natural landscapes preservation (National Parks and Nature Reserves Law of 1963 and the Law of the Protection of Vegetation of 1950).

The general average of sparsely vegetated areas decreased from 32 percent in 1944 to 10 percent in 1990, while areas with a high vegetative cover increased from 14 percent to 44 percent at the same period of time. By tracing the trends of vegetation change in the different study locations for the three categories of coverage we have charted four different types of vegetation processes:

- Natural recovery:

This process is represented by two parameters: the expansion of areas of heavy vegetation coverage and the transformation of areas of moderate vegetation cover into thick cover.

One should note that these results correlate with new findings of Kutiel (1993) and Broide, et al., (1996) who examined the process of vegetation renewal after fires.

- Recovery linked to afforestation:

Vegetation recovery rates were enhanced due to afforestation activities mainly by the KKL. These activities were widespread throughout the Carmel region and mainly during the 1960's and the beginning of the 1970's.

- Disturbance due to grazing and woodcutting:

Settlements having a significant proportion of agricultural land use are showing a delay in the vegetation development rate in open areas.

- Disturbance due to the expansion of built-up areas:

Vegetation recovery since the 1940's is a most prominent in the open areas of Mount Carmel region. The main threat to this positive phenomena is from the expansion of built-up areas. Controlled grazing in these areas may help in preserving not only the ecological values of this landscape but also allowing the continuation of some characteristics of the local population' traditional culture. Another advantage concerned improving the forest structure and by that reduction of fire threats (Pervolozki, 1992).



This study presents the theoretical principles, the methodology, and the use of Matrix analysis of landscape transitions by means of a Geographic Information System, and employs, for the first time in Israel, a quantitative method for measuring changes over a long period of time. The relationships between man and the environment have been presented in the past as being reciprocal ones, and as two separate systems--nature and man. The latter is an "exterior" force, creating disturbances and stopping them (Naveh and Lieberman, 1984). Only for the past few years have we begun to see studies pertaining to landscape transitions in the world as slow quantitative changes. This subject is still at its very beginning. In none of these papers was there a combination of a number of landscape methods over a relatively long period of time for a good number of locations. Studies which pertained to an analysis of the landscape of Israel were concerned with descriptions of the landscape and settlement processes in a qualitative manner (Ben Artzi, 1986, 1996; Grossman et al., 1993).

Because of the rise of awareness of the topic of open areas, studies have begun to appear dealing with an empirical analysis of the landscape (Feitelson, 1995). Our study presents an integral landscape system in which man lives and works and influences nature "from the inside." Even though the general trends of landscape development on the Carmel were well-known to Israeli scientific, the dynamics and rate of the processes were not studied quantitatively using methods of remote sensing. The scientific importance of this type of work results from the opportunity to use the same methods in different places and to compare the results despite differences in structure, characteristics, and function.

The use of landscape transformation matrices is a basic instrument for this purpose. The matrices were constructed by building layers of data in a regional geographic information system, and by overlaying each pair of successive layers. The rates of landscape transition were calculated by these matrices. They pointed to rapid processes of change on the Carmel -- urban encroachment at the expense of agricultural areas and natural vegetation. The continuation of these trends will undoubtedly bring about sharp conflicts between the needs for land for agriculture and building and the desire to preserve natural landscapes, the Carmel National Park, and the valley bottom landscapes which have been renewed on the periphery of Haifa.

The new methodology of matrix Land uses analysis present the analytical computerized approach to study of Land uses. It is hoped that it will broaden and deepen the study of landscape systems in Israel and enable its comparison with other Mediterranean landscapes.

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