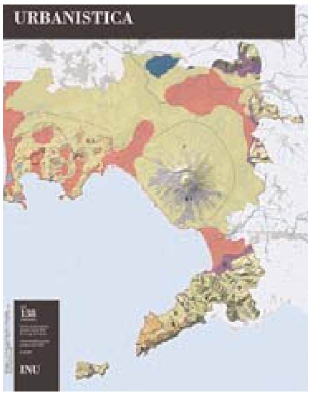

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Interpretational figures and methods for knowledge and evaluation of land consumption: the transition matrix

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This article will deal exclusively with the methodological system applied to the subject of 'land use/land cover'.
For a while we shall avoid referring to the concept of land consumption, preferring to talk about its transformation or change.
Changes in land use/land cover can be shown by means of a graph (Eea 2006): the triangle of transformations (see on p. 111, above). At the top of the triangle there are the fundamental land uses/land covers (urban, agricultural, natural) while the sides represent their transformations.
On p. 111, above, makes it possible to conceptualise the various possibilities for transforming the land from one to another, identifying certain fundamental properties that can be applied for interpreting the process. These are:
1. Type of transformation
a. Equivalent: a land use/cover is changed to another within the same category of origin.
b. Non equivalent: a land use/cover is changed to another from a different category than that of its origin.
2. Duration of the transformation
a. Permanent: land cover A is transformed to land cover B and can no longer be reversed (or it is highly unlikely);
b. Transitory: land cover A is transformed to land cover B and can be returned to land cover A (or it is very possible).
3. Outcome of the change
a. Artificial: the changed cover results in a loss or a major modification of the properties and the natural and environmental relationships that existed or potentially existed before;
b. Semi-natural: the change results in a modification that renews cyclically, but not a loss, of the properties and the natural and environmental relationships that existed or potentially existed before;
c. Natural: the change results in a regaining or restoring of the properties and the natural and environmental relationships compatible and appropriate for the site and the context.
Alongside the properties of the change it is possible to also consider the role which the type of cover of the land occupied or being occupied can acquire in the process of transformation:
a. Dominant: in this case, a land cover A is frequently what replaces other types of cover, but is rarely replaced by others;
b. Recessive: a land cover A is frequently overtaken by a certain class of cover, but rarely occupies and changes covers of other classes.
An example of equivalent change is urban regeneration where a new urban coverage replaces and renews a previous urban coverage. In this case, the duration of the transformation is permanent because the new coverage is intended to last 'forever', or at least more than two or three generations.
Turning agricultural land to natural cover can, after a certain time, be reversed, and this is why such transformations are classified as transitional.
Instead land consumption can mainly be considered as a non-equivalent, permanent and artificial transformation.
The schematic conceptualisation presented is linked to the methodology of the transition matrix, used in various studies in literature and also at an institutional level by subjects such as the European environmental agency (www.eea.int.eu) for identifying, monitoring and quantifying the transformations of use and coverage of land.

Transition matrix

If the data on land cover between two points in time are available, it is possible to find out the total of the surface areas transformed, the types of cover introduced to the land and the types that have been changed. The method for producing this collection of information is known as the calculation of the transitions and is based on the compiling of a matrix called the transition matrix (see fig. p 111, below).
The matrix is based on flows, in other words, on the transformation that a certain cover available at time t0 undergoes in a specific time period ?t = (t1 - t0). The input flow, shown on the lines, is represented by the covers at time t0; the exit flow, on the colomn, is represented by the cover at the final time t1. In the matrix cells is shown the amount of the surface area (hectares or m2) transformed. In the cells of the main diagonal is shown the value of the surface area of a certain category of land use which has remained unchanged in the time period ?t.
The matrix method therefore makes it possible to immediately obtain the absolute value (in hectares or m2) of the areas transformed by a cover (a) at time t0 to a cover (b) at time t1. For example, the value which is shown in the cell formed by crossing the line 'Nature 1999' with the column 'Urban 2004' is to be interpreted as the total of the surface area which, in 1999, had a natural cover and which was transformed in 2004 into urban cover.
The transition matrix therefore makes it possible to organise the data so that they produce certain interpretations for evaluating the environmental effects as well as the planning strategies. Some transformations have a different environmental impact from others.

The initial data for input to the transition matrix

For compiling the transition matrix it is necessary to have at least two geographic databases (raster or vector), one for each time threshold established.
These data or theme sets must be superimposed by a Gis intersection operation in order to achieve a further theme set representing the areas that have remained unchanged and those, instead, which have undergone changes. If vector theme sets intersect, polygons are obtained and, in the case of raster theme sets there will be obtained again just pixels.
Each polygon or pixel resulting from the intersection will be characterised by a pair of attributes: 'original land cover' and 'final land cover', which assign it to just one cell of the transition matrix. Each cell of the matrix will therefore contain the sum of area values of the polygons or pixels with the same pair of attributes.

The evaluation indicators

The evaluation of the transitions can be represented by many indicators. Below are shown some that are able to measure:
- the state of the cover at a certain moment;
- the rapidity of the transformation;
- the variation rates;
- the per capita size;
- the incidence of the transformations compared to the stock of original land cover. This fundamental indicator can only be calculated with the transition matrix method.
To the indicators are added the direct measurements taken from data such as the surface areas transformed between two time thresholds t0 and t1.

Composition indicators
In addition to the direct measurements (the surface areas), this category also includes the coefficients of cover i.e. the ratios of surface areas with a certain cover 'i' to the total surface area of the territorial unit taken as reference (a fictitious geometrical area or an administrative area such as a municipality). This means being able to calculate:
- urbanisation coefficient: Surb/Stot;
- rural coefficient or agricultural cover: Sagr/Stot;
- naturalness coefficient or natural cover: Snat/Stot;
- woodland coefficient or wooded cover: Sb/Stot.
The coefficients can also be obtained considering as the denominator the total surface areas net of the water areas (not modifiable) or, except for the urbanisation coefficient, also excluding the urbanised areas because no longer reversible and which can therefore no longer be turned to agricultural or natural use/cover.

Rapidity indicators
This category includes the rates of change of the cover type i.e. the ratios of the variations in the cover 'i' in the time interval (t1 - t0) to the total of the cover 'i' at the initial time t0. These indicators provide an interpretation of the rapidity with which certain types of cover increase or decrease.

Rates of variation
This group of indicators is given by the result between the changes in cover 'i' in the time interval (t1 - t0) and the time measure of the same interval (t1 - t0). In this case, the transformation values obtained are by days, per year, per two years, etc. This group of indicators provides a measure of the speed of transformation, making it possible to guess how long it might take for the transformation processes to alter the existing landscape structures.

Per capita indicators
One of the options possible for normalising the territorial magnitudes is the one that involves weighting the magnitude in relation to the number of resident inhabitants. Generally, when the value of the urbanised areas per inhabitant is high, this means that the urban spread is greater. Also the rapidity indicators can be efficiently expressed by normalising their numerical value with the number of inhabitants. In the same way, the simple figure of the surface area transformed between two time thresholds t0 and t1 can be related to the number of inhabitants.

Incidence indicators
This group of indicators is probably the most interesting and is the one that can be calculated only if the transition matrix has been completed. The percentage indicators measure the transformation of a certain cover 'i' at the expense of a starting coverage 'j', compared to the stock of cover 'j' initially existing. For instance, the urbanised cover accomplished in the time interval ?t = (t1 - t0), only regarding the part that has occupied previous agricultural use/covers, is compared to the initial stock of agricultural cover (t0). In this way, there is directly compared the transformation with respect to the resource that it, itself, has transformed and it is made possible to 'weight' the responsibility of the 'transforming' coverage. This is a method that shows the responsibility of the driving forces as well as the effect of the transformation on the land resource. These indicators are usually measured as a percentage.
- Rate of urban transformations on agricultural land compared to the initial agricultural stock: (URB?t)su_agr/AGR t0 [%]
- Rate of urban transformations on natural land compared to the initial natural stock: (URB?t)su_nat/NAT t0 [%]
- Rate of agricultural transformations on natural land compared to the initial natural stock: (AGR?t) su_nat/NAT t0 [%]
- Rate of natural transformations on agricultural land compared to the initial agricultural stock: (NAT?t)su_agr/AGR t0 [%] - […]
In theory, these indicators can also be calculated for the urban areas turned to agriculture uses for example but, in practice, will have zero or next to zero values.

Application of the method: transformations in Lombardy between 1999 and 2004
The methodology of the transition matrix has been applied to the Lombardy territory. The starting figure available consists of two land use/cover maps, in raster format, relating to the years 1999 and 2004, with a spatial resolution of 30x30m, produced on the basis of a key which includes 19 classes of land use/cover, processed by the Arpa Lombardia Remote sensing laboratory based on Landsat-Tm (Thematic mapper) satellite images. Extrapolating data made it possible to compile the transition matrix of table 1, on p 112, which was only organised on 11 classes of land coverage (Pileri 2008). In table 2, on p. 113, there are shown the surface areas changed and the percentage indicators calculated based on a series of transition matrices organised to reveal the transformations between 1999 and 2004 in the two areas surrounding Milan and Brescia.