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EVALUATION AND PLANNING CONTROL OF THE ECOSYSTEM FRAGMENTATION DUE TO URBAN DEVELOPMENT

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ABSTRACT

To measure the ecosystem fragmentation phenomena due to urban sprawl, it is possible using indicators that consider some functional characteristics, such as shapes and dimensions of the urban objects (road networks and urbanised areas), and ecological and ethological characteristics of target animal species. On the bases of these parameters we can obtain models for different urban fragmentation scenarios, where each model is related to a range of indicator values.

The new framework for the territory, drown by the plan, will be more or less suitable for the movement of the species that live around and will be possible to adjust the impacts of the urban transformation on the ecosystems and natural landscapes, analysing this suitability through biopermeability evaluation.

The data and the methods used during the research program that we have inserted in the present paper are relative to study area of the Italian Central Apennines, a mountain place where it is possible to find natural areas and complex eco-mosaics, with species of fauna of international importance, and numerous small and middle urban areas "plunged" in the ecological networks.

METHODOLOGY USED

Different kinds of urban sprawl on the territory cause the ecosystem fragmentation phenomena which the planning tools often are not able to control.

It is possible to measure these phenomena through some indicators that consider functional characteristics, shapes and dimensions of the urban objects (road networks and urbanised areas). According to these parameters we can obtain the models of different urban fragmentation scenarios, where each model is related to a range of indicator values.

Then some animal species characteristics have been considered, such as trophic specialization, sensibility disturbance, habitat fidelity, size of body, movement velocity and ability to overcome barriers (Verboom 1991; Checchi 1999; Foppen *et alii*, 2000; Alterra 2003) operating a classification of these characters according to a close and qualitative scale of values, formed by three degrees where, from 3 to 1, we have a decreasing urban environment incompatibility. Using this evaluation it is possible to obtain an index AIFAI "Animal Incompatibility to Fragmentated Areas" that has a correspondence with the different ranges of the other analysed indexes, as IFI (Infrastructural Fragmentation Index) and UFI (Urban Fragmentation Index), established from the settlement framework of the territory (Romano & Tamburini 2001; Romano 2002).

At the same time we get the relations among the cited values of fragmentation indicators and the other classic parameters that the planners use to regulate density and distribution of the future urbanised areas on the territory.

Eventually the goal of the applied methodology is to realise an analytical linking between these last parameters (already used in Italy since seventies years and now consolidated in the technical and social culture) and the results in terms of ecosystem fragmentation and the effects on some important zoological groups which have a particular conservation importance.

The data and the methods used during the research program that we have inserted in the present paper are relative to study area of the Italian Central Apennines, a mountain place where it is possible find natural areas and complex eco-mosaics, with species of fauna of international importance, and numerous small and middle urban areas "plunged" in the ecological networks.

The paper is largely based on the studies carried out in 1998-2002 for the Life Econet Project, "A European project to demonstrate sustainability using ecological networks",

LIFE99 ENV/UK/000177, (Cheshire County Council 1999) and on other research national programs as Planeco Project (Romano 2000).

DATA AND INDICATOR PROCESSING

Urban fragmentation effects

Settlements, formed by urbanised areas plus the areas used for road, production and services infrastructure, lead to the fragmentation of ecosystems, which can be broken down into three main forms affecting natural habitats and species living in the areas concerned:

- the spatial division caused by linear infrastructure (road and technological networks);
- the division and elimination of space brought about by the expansion of developed and urbanised areas;
- the disturbance caused by movements, noise and lights.

The foregoing forms of fragmentation may be broken down into two types:

Current fragmentation which can be observed today in the area and which, for this reason, contributes significantly to the current geography of ecosystems and conditions the present-day layout of distribution areas and the relations between species. In other words, it may be considered part and parcel of the current ecological structure of the area.

Potential fragmentation is what the geography of the ecosystems will be subjected to, as a result of the implementation of planning forecasts that are either in force today or are being developed. It affects mostly short and mid-term environmental scenarios and the reorganisation of the system of distribution areas and species-specific relations that will take place, following the implementation of the plan and after a period of adjustment.

The indicators developed to describe the role and extent of fragmentation of the environment caused by current and potential settlements are the following:

The fragmentation caused by road infrastructure may be assessed by means of separate indices according to the type of infrastructure (motorways, railways, main roadways, local roadways, and overall standardised index) depending on the different features of environmental obstruction that each category entails for wildlife.

Infrastructural fragmentation may be measured using the Infrastructural Fragmentation Index (IFI):

$$IFI = \sum (L_i * o_i) * N_p/A_t * p \qquad (1)$$

where:

L_i = Length of the infrastructure (excluding tunnels and viaducts);

o_i = Obstruction coefficient of the infrastructure, depending on the type of infrastructure and traffic flow;

N_p = Number of parts where the reference territorial unit is fragmented by the road network;

A_t = Area of the reference territorial unit;

p = Perimeter of the reference territorial unit.

In relation to obstruction coefficient, o_i=1 in the case of motorways and railways (total obstruction due to side fencing), while, in the case of roads with a high volume of traffic (with significant obstruction due to noise and permanent movement), the obstruction coefficient o_i is expressed as a function of the traffic flow on the section of the road considered.

In a given road section, with a traffic flow equal to n vehicles per hour, the time during which the same section is free from transit is equal to:

$$\Delta t = 1/n \tag{2}$$

If Δt are equal, then the probability that wildlife will successfully cross the road depends mainly on the theoretical speed of movement of the species, the width of the road and the length and width of transiting vehicles.

These considerations clearly show that it is possible to develop a very detailed coefficient of biological obstruction caused by roads, at scales where numerous variables can be used.

If one remains at a territorial level of indicator processing, the latter may be simplified by attributing an obstruction coefficient equal to the one of side-fenced infrastructure (100%) when the traffic flow is equal to or greater than 60 vehicles/h. This value tells us that the section of the road is free from transiting vehicles for one minute on average.

Therefore, the obstruction coefficient may be related to the average daily traffic flow per hour through the following relation:

$$o_i = n/60 \tag{3}$$

where **n** is the traffic flow expressed as the number of transiting vehicles per hour.

In general, the same road sections have very different traffic flows depending on the season and times of the day and night. In this respect, the fragmentation effect of a road varies undoubtedly and may be further assessed once relative data are collected.

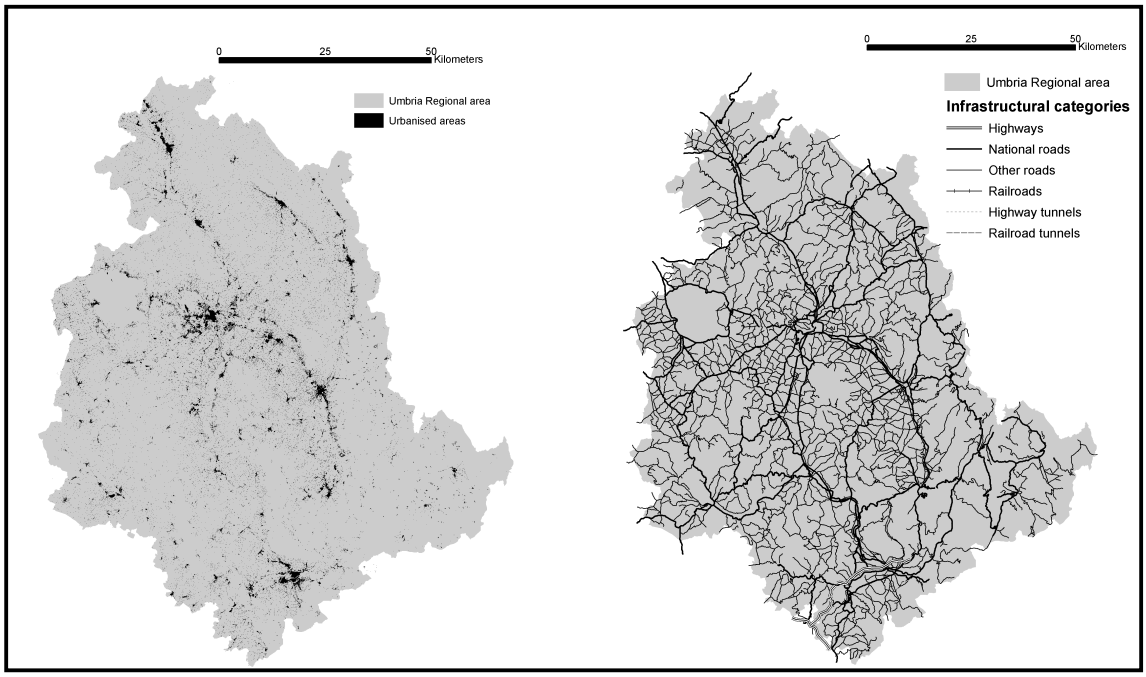


Figure 1 – Examples of urban and infrastructural systems density and geography in Central Italy (Umbria Region)

On the basis of the consideration that, if the size of settlements is the same, then the circular, polarised shape is the one that minimises environmental fragmentation, linear urban fragmentation can be measured using the Urban Fragmentation Index (UFI):

$$UFI = \sum(L_i * \sqrt{S_i})o_i / A_t \quad (4)$$

where:

L_i = Maximum size of the linear urban barrier of the i type;

S_i = Surface of the urbanised area of the i type;

A_t = Area of the reference territorial unit;

o_i = Coefficient expressing the level of obstruction that is characteristic of the various types of urbanised areas for the species considered. By using a simplified rationale, to obtain an indication at territorial level, the following values may be viewed as significant:

a) Industrial areas and the like: 100%

Presence of concentrated pollution, heavy traffic, noise, lights and disturbance even at night, presence of large paved areas, general lack of green areas.

b) Business districts and the like: 80%

Presence of large paved areas, night lighting, significant daytime traffic flows, greater general presence of green areas and vegetation compared to case a).

c) Intensive residential areas : 60%

Presence of concentrated pollution, noise, daytime disturbance, general presence of green areas and vegetation that is more distributed and widespread than in case b).

d) Extensive residential areas: 40%

Scattered housing, greater spreading of disturbance, presence of vegetation and green areas, both within private plots and in public areas, generally greater compared to case c).

Sensitiveness towards the use of land for widespread urbanisation can provide a significant indication for the development of environment-friendly planning tools. This involves understanding how an area will respond to the use of land due to the gradual expansion of urbanised areas, following the creation of some favourable conditions related to the geographical and social structure, as well as local and external economic factors.

The territorial significance of indicators, that is to say their ability to describe a given relationship between settlement and environment, is supported by a sampling procedure used to find a matching between the values of the indicators and the typological characteristics of the settlement. The sampling procedure makes it possible to link different ranges of calculated indices to the features of urban areas and their specific geography and landscape.

The use of indicators of fragmentation caused by settlements is useful both to represent the current condition of the phenomenon and to develop future scenarios tied to forecasts made using urban development tools that either exist already or are being developed.

UFI	IFI	Fragmentation landscapes	Planning indicator of territorial use (Ut)	Planning indicator of land use (Uf)
Over 100	Over 5000	Presence of high-density urban settlements concentrated along complex infrastructural lines or coastlines;	Over 5000 mq/ha	Over 0.90 mq/mq
Between 50 and 100	Between 3750 and 5000	Presence of medium-density urban settlements distributed along the bottom of valleys or coastlines;	5000>Ut> 3000 mq/ha	0.90>Uf> 0.65 mq/mq
Between 10 and 50	Between 2500 and 3750	Presence of medium-density urban settlements distributed along the bottom of valleys, intermountain basins and hilly belts, associated with intensive farming;	3000>Ut> 2000 mq/ha	0.65>Uf> 0.40 mq/mq
Between 5 and 10	Between 1600 and 2500	Presence of intensive rural settlements scattered mainly along hilly belts and on the bottom of valleys;	2000>Ut> 1000 mq/ha	0.40>Uf> 0.25 mq/mq
Between 2,5 and 5	Between 750 and 1600	Presence of extensive rural settlements scattered mainly along hilly belts and on the bottom of valleys;	1000>Ut> 0 mq/ha	0.25>Uf> 0.00 mq/mq
Less than 2,5	Less than 750	Mainly mountainous natural and semi-natural areas.	About 0.00	About 0.00

Table 1 - Fragmentation Indexes Sampling Table (Fragmentation Landscapes)

The parameters U_t and U_f are those that are used in the Italian planning tools to control the planning action in terms of build quantity and distribution on the territory. The values of these parameters can be found in a particular document enclosed to the plan, called “Technical Rules”.

The parameters have the following formulas:

$$U_t = S_u/S_t \quad \text{and} \quad U_f = S_u/S_f \tag{5}$$

where:

S_u is named “Useful Surface” (the whole floor area that it is possible to realise in a considered planning zone, scattered on all builds in the same zone);

S_t is named “Territorial Surface” (the whole area of a considered planning zone, that include the residential areas, the road areas and the utility areas);

S_f is named “Land Surface” (part of St relative to residential areas).

Species fragmentation incompatibility

A significant correlation between the traditional urbanistic parameters, using the

IFI/UFI scores, and the biopermeability levels of a territory in function of a set of target animal species, depends by different factors that partially we can define "environmental", such as: geographical location of the urbanized area, also with respect to the typology of the surrounding territory; morphology, position and distribution of the extant fragmentation elements; and partially by factors that we can define "intrinsic", depending by autoecology and ethology of the target species considered.

To this regard, the aim of our study is to supply a general profile of animal species that reply in different way to the presence of barriers, in dependence of some their ecological and ethological characteristics as reported in Tab. 1. Each of the characteristic considered, called from now onwards "factors", was subdivided in three different levels and a numeric value was attributed to each of them. These values are highest in corrispondence of the increased difficulty of the animal species to overcome fragmentation elements.

For the calculus of the "animal incompatibility to fragmentated areas" index (AIFAI) we used the following formula:

$$\mathrm{AIFAI} = \frac{\sum_{k=1}^{n} F_k^2}{n} \tag{6}$$

where F is the value of the n^{th} factor considered and n the number of factors;

$$\mathrm{AIFAI_{min}} = 1 \quad \text{and} \quad \mathrm{AIFAI_{max}} = \frac{\sum_{k=1}^{n} x^2}{n} \tag{7}$$

where x is the maximum value of each factor considered.

It is important to underline that we have considered the sum of squares of every single factor because this choice allows to point out the contribute to the index by the species that show the maximum value at least in one of the factors considered.

The data reported in this paper must be considered as preliminar. At present-time, a wider and deeper study is in progress to define better the most significant factors and respective levels useful to evaluate the reply of the target animal species in presence of fragmentation elements. Anyway, we have reported in Table 3 an attempt of correlation between the IFI/UFI scores and the AIFAI, referring also to some common Apennine species of vertebrates for each category considered. The species used for our study are amphibians, reptiles and mammals. No bird was considered because these animals generally show a very good movement ability through the flight, and so they do not supply a fine information about the urban fragmentation.

1	**Trophic specialization**	Stenophagous Oligophagous Euryphagous	**3** **2** **1**
2	**Sensibility disturbance**	High Medium Low	**3** **2** **1**
3	**Habitat fidelity**	Stenoecious Oligoecious Euryecious	**3** **2** **1**
4	**Size of body**	Large Small Medium	**3** **2** **1**
5	**Movement velocity**	Low Medium Fast	**3** **2** **1**
6	**Ability to overcome barriers**	Scarce Medium Good	**3** **2** **1**

Table 2 - Factors and levels used for the calculus of the "animal incompatibility to fragmentated areas" index (AIFAI).

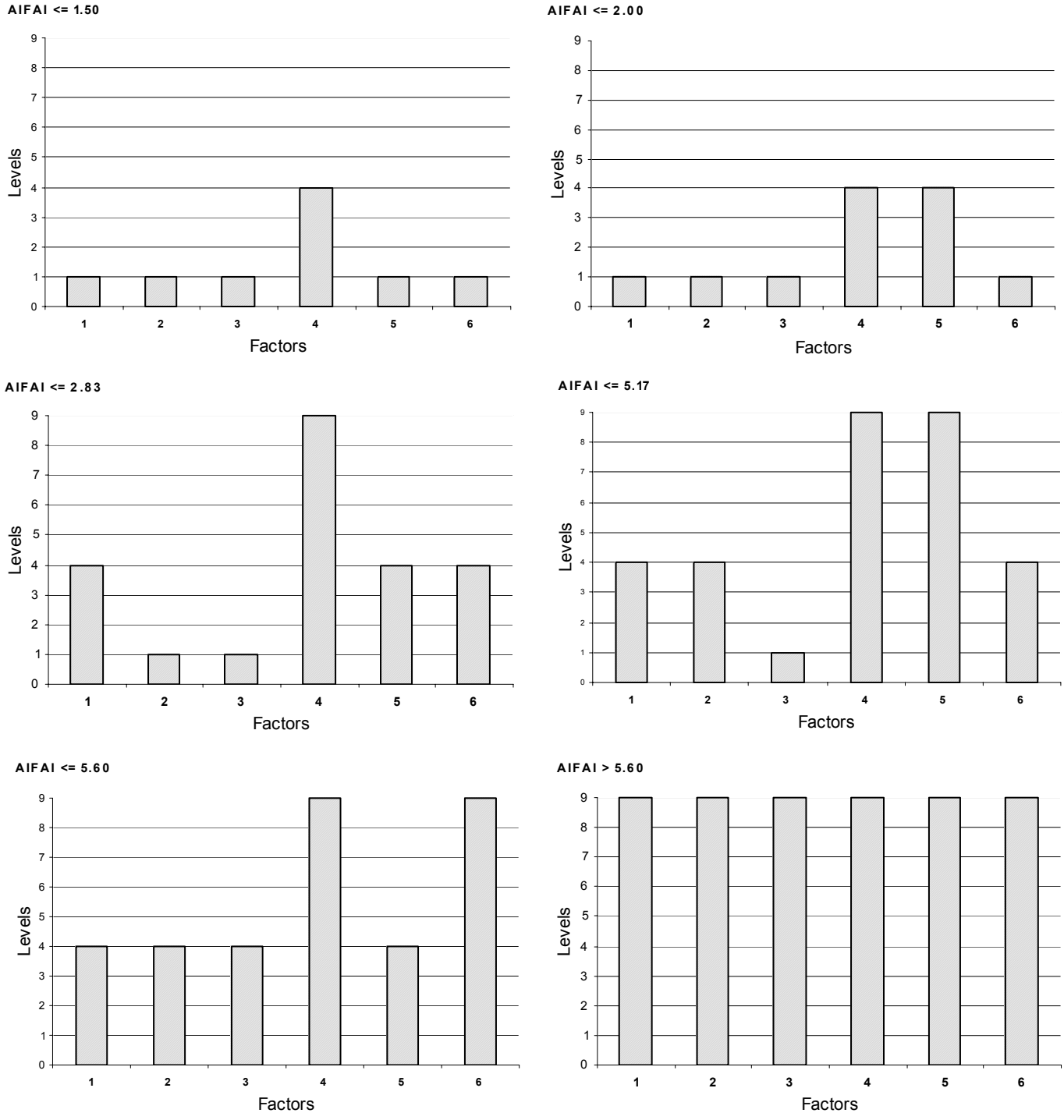


Figure 2 –Variation of the factors in relation to the AIFAI values

CONCLUSIONS

Very interesting is the relation among the fragmentation indexes, the urban parameters and the compatibility characters of the species in order to different behaviour kinds. As

we said before, in the Italian planning experience the urban parameters have not been never used for regulating the urban transformations with care to ecosystem framework, but have been used just as tools to control the physical settlement dimension and the amount of the residential areas and the utilities structures in relation with the population quantity and spatial distribution.

When we reach to find the link between these urban parameters and the other environmental characters relative to the natural system and species needs, we have a true possibility to give at the land planning instruments an other important environmental awareness.

One of the most interesting result is the threshold values obtained. In particular for $10<UFI<100$, $2500<IFI<5000$ and $AIFAI \leq 2.83$, we find an environment where only few species have the possibility to live and move.

For $UFI<10$, $IFI<2500$ and $AIFAI>2.83$ we find a very good environmental quality with a potential presence of a large number of species.

In this way we'll can realise the credible scenarios about the environmental fragmentation conditions following the management of a plan tool. The new framework for the territory, drown by the plan, will be more or less suitable for the movement of the species that live around and will be possible to adjust the impacts of the urban transformation on the ecosystems and natural landscapes, analysing this suitability through biopermeability evaluation.

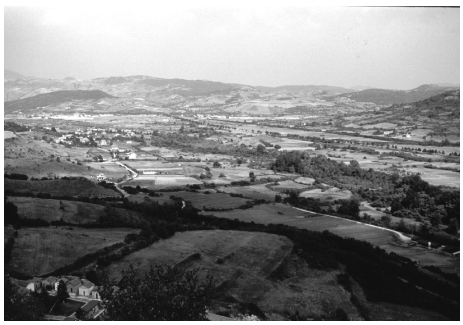
In this preliminary phase we have found, as it is possible to see in Table 3, the existing relations among the different indexes and parameters already cited.

These relations have been experimented in the study area of the Central Apennines and so will be interesting to understand if the same values indicate the same phenomena in other environmental and urban systems.

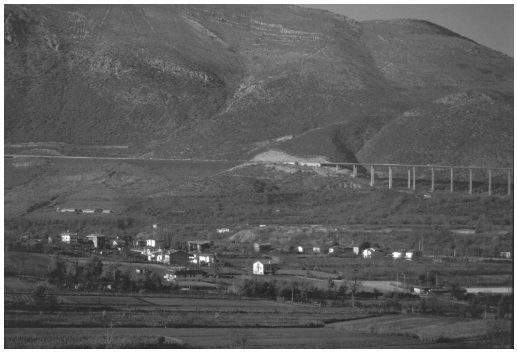
UFI > 100 IFI >5000
AIFAI ≤ 1,5

50 <UFI < 100 3750< IFI ≤5000
AIFAI ≤ 2.00

10 <UFI < 50 2500< IFI <3750
AIFAI ≤ 2.83



5 <UFI < 10 1600< IFI <2500
AIFAI ≤ 5.17



2.5 <UFI < 5 750< IFI <1600
AIFAI ≤ 5.60

UFI < 2.5 IFI <750
AIFAI > 5.60

Figure 3 – Examples of index thresholds and environmental models in the Central Italy

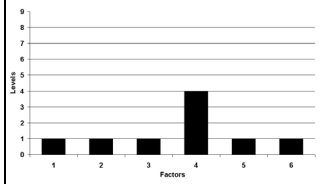
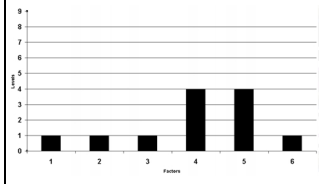
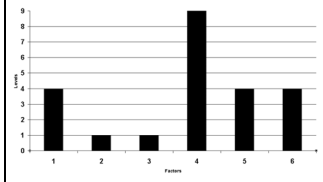
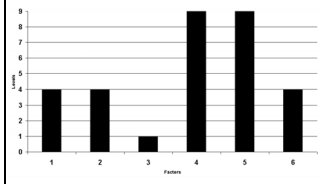
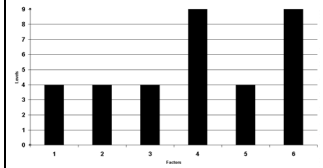
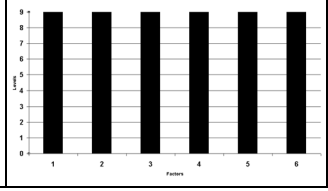
UFI	IFI	Fragmentation landscapes	Planning indicator of territorial use (Ut)	Planning indicator of land use (Uf)	Factors and levels histograms	AIFAI	Reference Apennine Species
Over 100	Over 5000	Presence of high-density urban settlements concentrated along complex infrastructural lines or coastlines;	Over 5000 mq/ha	Over 0.90 mq/mq		≤ 1.50	--------
Between 50 and 100	Between 3750 and 5000	Presence of medium-density urban settlements distributed along the bottom of valleys or coastlines;	5000>Ut> 3000 mq/ha	0.90>Uf> 0.65 mq/mq		≤ 2.00	Red Fox Wall Lizard Ruin Lizard
Between 10 and 50	Between 2500 and 3750	Presence of medium-density urban settlements distributed along the bottom of valleys, intermountain basins and hilly belts, associated with intensive farming;	3000>Ut> 2000 mq/ha	0.65>Uf> 0.40 mq/mq		≤ 2.83	Hedgehog Common toad
Between 5 and 10	Between 1600 and 2500	Presence of intensive rural settlements scattered mainly along hilly belts and on the bottom of valleys;	2000>Ut> 1000 mq/ha	0.40>Uf> 0.25 mq/mq		≤ 5.17	Roe Deer Red Squirrel Beech Marten Polecat Badger Dark Green Snake Green Lizard
Between 2,5 and 5	Between 750 and 1600	Presence of extensive rural settlements scattered mainly along hilly belts and on the bottom of valleys;	1000>Ut> 0 mq/ha	0.25>Uf> 0.00 mq/mq		≤ 5.60	Wolf Brown Bear Italian Crest Newt
Less than 2,5	Less than 750	Mainly mountainous natural and semi-natural areas.	About 0.00	About 0.00		> 5.60	Spectacled Salamander Fire Salamander

Table 3 – Relation among different environmental, urban and eco-ethological analysed indexes

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