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EVALUATION OF URBAN FRAGMENTATION IN THE ECOSYSTEMS

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Abstract

In the Apennines, the peninsular chain of Italy, it is possible to find an environment formed by different kinds of ecosystems. Urban areas with very different dimension are located among large spaces with wild lands and mountains that have the top near 3000 m above sea level with important endemic species which have their habitats round urban areas, highways, railroads, industrial and intensive agricultural areas.

One of the most important problem of the Planning Sciences and of the applied Natural Sciences is now how to realise the planning instruments which could consider the ecological problems in terms of relation between biodiversity characteristics and needs of urban development.

The first phase of these researches foreseen the analysis of the ecological settlement trough the realisation of the "ecosystemic map". In the second phase the structure of ecosystem is compared with the configuration of the planning system, that insert in the territory framework further barriers and other ecological fragmentation elements.

The characteristics of the human fragmentation action can be measured with particular indicators that are related at the shapes, the kinds and the distribution of the urban areas and the infrastructural network. The barriers conditions that we have at present and in the future can be expressed trough scenarios which have the indicator values as interpretation parameters.

These scenarios will become instruments of decision support for the planning procedures to avoid that the new planning instruments can realise too serious and irreversible environmental fragmentation conditions.

If we have advanced and analytical information about the relationship between the urban and ecological settlement of the territory will be possible to modify the structure of new urban expansion areas, maintaining the social economic performance of the land project and minimising the environmental impact of the urban planning .

INTRODUCTION

The growing awareness of the environmental problems caused by the fragmentation of habitats and the isolation of biotic populations has led us to consider settlements, which have grown rapidly changing in both shape and volume, as an element of “disturbance”, a barrier and a disruption of existing environmental balances, which vary considerably in nature and involve innumerable ecosystems.

As a result, this cultural approach has led us to consider the technical aspects of a plan differently, especially when these take the form of parameters used to measure the effects of settlements on ecosystems, and in particular the fragmentation of the latter caused by urbanisation and infrastructure in their current physiognomy, but above all in their foreseeable, planned or potential one, through the development of active scenarios.

As a tool, urban planning has an impact on fragmentation at different levels, both if it is aimed at rehabilitating the city and municipal area, or envisages the development and expansion of settlements.

It is possible to distinguish a first ecosystem-shearing effect caused by the road network, which, depending on the type, size, morphological location and traffic, can obstruct wildlife movement of varying significance and has been tackled often in specialised literature (Spellerberg, 1998). Infrastructural fragmentation is extremely widespread throughout the territory, but it is always generally possible, from a technical point of view, to undertake action to mitigate it, although costs may vary considerably.

The second cause of environmental fragmentation is urbanisation of the territory which is a highly complex problem to overcome, since it is very difficult to remove or even mitigate due to reasons tied to private interests and the type and scope of the actions needed (Walmsley, 1995) .

This is why it is essential that before being applied, planning tools should foresee the consequences of the insularisation of ecosystems, especially those caused by urbanisation, and succeed in making the draft plan compatible with this phenomenon, which in other words is one of the attributes of the “sustainability” of the same plan.

A territorial plan may effectively help monitor environmental fragmentation, if firstly it is based on the necessary in-depth ecological knowledge and, then if it succeeds in developing adequate indicators that may be used to create alternative scenarios on the basis of which transformation decisions can be taken and adjusted.

In order to trace the pre-plan layout of the ecosystem, it is necessary to have some knowledge about the area in question, especially with regard to the following (ANPA, 2001):

- ?? Location and size of potential and actual distribution areas of target species;
- ?? Potential population dynamics;
- ?? Geography of relations among distribution areas;
- ?? Documented presence of the species;
- ?? Relations of the species with the current settlement structure;
- ?? Critical and risk conditions.

The starting layout of the ecosystem will tally with a given configuration of infrastructure and urbanisation that can be measured using appropriate fragmentation indicators.

By making the aforementioned measurements, in several exemplifying cases, it is possible to sample indicators and make them capable of giving us the general geographical, landscape and ecosystem configuration of the area, through the values they provide.

After having made this adjustment, it should be possible to create evolutionary scenarios that can give the plan that is being developed a reference time perspective of its presumable effects in terms of changes to the ecosystem of the area, by applying fragmentation indicators to a dynamic condition.

Some indicators, capable of describing the current role played by a settlement in determining fragmentation, are fundamental in the interpretation of the conditions of environmental continuity. Several indices have been developed that are linked to different forms of fragmentation, known as “current” (the existing fragmentation that conditions the current layout of the ecosystem), “potential” (the fragmentation that is very likely to be achieved, following the implementation of settlement forecasts made using the town planning tools in force) and “likely” (depending on the features of the anthropic communities present in a given place and hence on their social structures, standard behavioural models of economic development, as well as a number of territorial characteristics) (Romano & Tamburini, 2001).

Fig. 1 – Scheme of environmental fragmentation condition “current” and “potential”

More specifically, it may be claimed that the size of the new settlement areas, their type and geometrical shape, the location of the new infrastructure network and their spatial relations and the way in which the land is currently used in those areas that are indicated in the plan as susceptible of “consumption” for the purposes of urbanisation, are all variables that may be expressed as parameters and that perhaps can give us a “measurement” of the fragmentation effect of scheduled works, in a given environmental context, through the implementation of relational algorithms and models.

It is clear that it is possible, although highly complex, to develop a relation between the fragmentation features of a plan, expressed by the geometry, topology and typology of the areas concerned, and the groups of species that probably could continue using the theoretical dispersion lines present in the area before the implementation of settlement development forecasts.

This is feasible if we have ecological-spatial data that allow us to have a more thorough understanding of the local planning approach and the economic and social reasons and thrusts underlying the project configuration.

It may be assumed that in any environmental setting it is possible to draw up a plan for the development of a settlement that has the same results (cubic capacity of buildings, urbanised area, creation of predetermined revenue established on the basis of position, spreading of the economic repercussions of the plan on a vast territorial scale, etc.), but at the same time minimises the fragmentation and disruption of existing ecosystems, provided that the geography and relational parameters of the latter are known (map of the layout of ecosystems).

The foregoing problem of opening the urban development plan to the need for expansion and movement, and not merely conservation of the statu quo, of living beings other than man, opens up a field of research that is in part new, at least for natural sciences, and most certainly for territorial sciences.

In this paper we will refer to the features of the indicators used in a study to analyse the forms of environmental fragmentation caused by urbanisation and to their use in the development of territorial planning tools.

DATA AND INDICATOR PROCESSING

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:

Infrastructural Fragmentation Index

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):

$$IFI = \sum (L_i * o_i) * N_p / A_t * p \quad \text{where:}$$

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, $\alpha_i=1$ 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 α_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:

$$t = 1/n$$

If t 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:

$$\alpha_i = n/60$$

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.

Fig. 2 – Values of IFI in the context of the Italian Central Apennines

Urban Fragmentation Index

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):

$$UFI = \sum (L_i * \alpha_i) \quad \text{where:}$$

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

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

α_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.

Fig. 3 – Typical development schemes of the urban areas and the trend of UFI

SAMPLING OF FRAGMENTATION INDICATORS

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	Typological features of settlements
Over 100	Over 5000	Presence of high-density urban settlements concentrated along complex infrastructural lines or coastlines;
Between 50 and 100	Between 3750 and 5000	Presence of medium-density urban settlements distributed along the bottom of valleys or coastlines;
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;
Between 5 and 10	Between 1600 and 2500	Presence of intensive rural settlements scattered mainly along hilly belts and on the bottom of valleys;
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;
Less than 2,5	Less than 750	Mainly mountainous natural and semi-natural areas.

Table 1 - Fragmentation Indexes Sampling Table

CONCLUSIONS

The topics that we have dealt with in this paper characterise environmental fragmentation studies both at a territorial and urban level. The attention paid to the use of indicators stems from the need to build a knowledge base for planning tools involving the effective use of sophisticated technology to simulate the effects resulting from territorial transformation decisions. The current technologies to develop and manage Geographical Information Systems (GIS) make it possible to adopt a broad, complex approach through scenarios, the physiognomies of which have to be appropriately supported by analytical descriptors capable of providing information on the evolution of phenomena in order to be able to intervene by means of adaptive control measures when dynamics diverge from the reference points fixed during planning.

If it is true, as it is, that environmental fragmentation and the insularisation of ecosystems are key elements to establish "sustainability" standards in land governance procedures, then it is essential that, as in the case of more consolidated forms of impact in the administrative and social culture (pollution, physical and landscape-related deterioration of the soil, etc..) ecosystem disruption become "measurable". It should become one of the indicators of urban and territorial quality that European guidelines, such as Agenda XXI, currently consider key and decisive to report on the efficiency of management and the corrections made to environmental management.

The use of environmental indicators pertains to the phase of acknowledgement and reconstruction of the current physiognomy of ecosystems in an area (before scheduled planning actions), the development of alternative forecast scenarios and lastly the monitoring and control of gradual outcomes following the implementation of the changes brought about by the plan.

The role of descriptors in the foregoing circumstances involves the fixing of univocal identification and recording criteria for indicators. These criteria will, of course, have to remain unchanged throughout the entire period of the process of design and adaptive control of planning tools.

The indicators will be applied systematically to the operational scale of the urban development tools considered (the most significant level is the municipal one) through standard procedures (places, time, method of data collection, etc..).

Numerous experiences have already produced indicators in the field of the ecology of landscapes and biogeography that relate to the consequences of the insularisation of habitats and the interruption of biological link corridors (Mac Arthur & Wilson, 1967, Forman, 1995). However, it is extremely difficult that these parameters can be added to the planning rules, if they are not re-adjusted, fine-tuned and assimilated with those that the urban development plan is able to understand and apply to the procedures to control changes to settlements.

With regard to the further development of indicators of environmental fragmentation caused by growing urbanisation, a study is underway to determine "potential fragmentation" descriptors that is linked to the "eco-ethology" of human beings and the thrust towards expansion and "territorial conquests" that they express incessantly (Heisey, 2000), provided that the environmental economic and social conditions for it to take place exist. This is a long-term phenomenon, the structure of which goes beyond the ordinary control capabilities of planning. To this regard, some analytical hypotheses have already been put forward, but are currently being tested and adjusted.

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