Predicting fragmentation effects of future planned infrastructure on wildlife habitats in protected metropolitan greenspace. The case of Collserola Park in Barcelona

Seán Cahill[1], Anna Tenés[1], Francesc Llimona[1], Raimon Reventós[1], Lluís Cabañeros[1] & Victor Bonet-Arbolí[2]

[1]Estació Biològica Can Balasc, Consorci del Parc de Collserola
Ctra. de l'Església, 92 – Barcelona,
08017, Barcelona
SPAIN
E-mails: sean@euronatura.com, tenes_a@yahoo.es, llimona@amb.es, reventos@amb.es, lluisc@amb.es,
(Phone: + 00 34 935 900 566, Fax: + 00 34 932 806 074)

Departament de Vertebrats, Facultat de Biologia Animal, Universitat de Barcelona
Avinguda Diagonal 645
08029, Barcelona
SPAIN
E-mail: bonet@porthos.bio.ub.es
(Phone: + 00 34 934 021 041, Fax: + 00 34 934 034 426)

Keywords: Collserola park, habitat fragmentation, metropolitan area, transportation infrastructure, roadkills, SIG, simulation, wildlife.

Abstract

Collserola Park is situated within the greater metropolitan area of Barcelona, close to the Mediterranean coastline. The park occupies some 8,000 ha of predominantly Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus ilex*) woodlands with a high diversity of wildlife habitats. Many wildlife habitats in Collserola park are now effectively isolated from those of other nearby natural areas by major transportation infrastructures and urbanised ground.
The General Metropolitan Plan for the Barcelona area envisages the development of further new infrastructure within and around the park in the future. Consideration of existing data on wildlife and habitats in the park, in combination with detailed GIS analyses of future scenarios which simulate the planned infrastructures foreseen, has allowed for a prediction of likely habitat fragmentation effects and other impacts on certain wildlife species in Collserola Park. If undertaken, certain planned new infrastructures could seriously jeopardise the long-term viability of certain wildlife habitats in Collserola park and thus undermine its overall ecological integrity.

Introduction

Recent publications have underlined the multiple fragmentation effects of transportation infrastructures on natural habitats, both internationally (Forman *et al.*, 2003; Trocmé *et al.*, 2002) and in Spain. (Rosell *et al.*, 2003). The Barcelona Metropolitan Area (BMA) suffers from a high degree of fragmentation due to the presence of infrastructures and urban growth (Marull and Mallarach, 2002), which gives rise to an advanced state of ecological isolation in the case of the Collserola mountains, situated beside the city of Barcelona.

This situation is far from improving, in spite of advances in our knowledge and understanding of fragmentation mechanisms and their effects on the natural environment. On the contrary, in the BMA there has been an acceleration of fragmentation processes in the habitats that still remain (Marull and Mallarach, 2002).

At present, there is a more or less effective protection of certain areas as nature parks, agriculture parks, etc., as areas of natural or semi-natural territory where traditional, current and/or sustainable land uses are maintained. Nevertheless, the ecological connections between many of these areas are at present deteriorating because of urban expansion and the development of new infrastructure. This is largely because in many cases the ecological value of green corridors between protected areas was not fully appreciated when the current spatial planning framework was developed.

In the specific case of Collserola Park, the fragmentation impact of transportation infrastructure is doubly severe, because on the one hand the park suffers from ecological isolation due to the ring of high volume roads, railways and urban fabric that surround it, and secondly the park is internally fragmented by these same elements (Figure 1). Its location at the heart of the BMA, with a population of over three million people, means that current and future pressure on wildlife habitats in Collserola is intense.

The main reference document for questions relating to territorial planning in the BMA is still the General Metropolitan Plan (PGM), which dates from 1976. Although in many respects this plan is clearly out of date, at least with regard to ecological considerations, it is nevertheless still in force almost 30 years after its elaboration, despite there being a very different territorial, social and environmental framework now than that which existed in 1976. In this sense, Marull and Mallarach (2002) alert to the fact that urban ground could cover as much as 22% of the surface area of the BMA if certain urban plans that are currently in force are finally developed. The implications of the PGM are especially relevant in the case of Collserola, given that in this plan there are several large transportation infrastructures which, as yet, are undeveloped.

The important advances in the science of landscape ecology (Forman and Godron, 1986; Pino and Rodà, 1999), combined with those of GIS techniques, permit quantitative analysis to be carried out on specific questions concerning the spatial pattern of landscapes, their composition, structure, etc., in both real and hypothetical situations (McGarigal *et al.*, 2002). In recent years a wide array of landscape metrics have appeared that help quantify aspects of the structure and functioning of landscapes. Such metrics can have implications not only for ecological interpretations, but also for sustainable spatial planning (Botequilha Leitão and Ahern, 2002). The present study aims to evaluate the current state of fragmentation of wildlife habitats in Collserola by quantifying different landscape metrics, and to simulate the additional fragmentation effects that could be caused by the possible future development of the main transportation infrastructures foreseen under the PGM scenario.

Fauna road casualties and habitat fragmentation in Collserola

The problem of fauna road casualties (FRCs) in Collserola has been treated in detail in a recent study (Tenès, Cahill and Llimona, 2003). Nevertheless, before entering into the questions relating directly to the analysis of habitat fragmentation in Collserola, it is worth commenting on the impact of FRCs in this protected area, given that this phenomenon is often closely tied to that of fragmentation.

Figure 1.
Collserola Park is crossed by several important transportation infrastructures. In the case of the Vallvidrera motorway and the railway, the barrier effect and the fragmentation of habitats are particularly intense due to the fact that they both have perimeter fencing and run parallel to one another.

FRCs affect a large number of vertebrate species in Collserola Park, with special incidence in the case of mammals, hedgehogs (*Erinaceus sp.*) and red squirrels (*Sciurus vulgaris*) being the most affected (Tenés *et al.*, 2003). For the species most frequently run over, roads represent a constant loss of individuals which can have negative consequences for their populations, aggravating their conservation status when combined with other problems they may face. This, for example, might be the case of the red squirrel, which has suffered a drop in population numbers in Collserola in recent years.

In the case of species such as the wild boar –one of the most affected by FRCs in Collserola accounting for 8.3% of all such incidences-, their large territorial requirements and high mobility means that they frequently have to cross roads in the park to move between resting and feeding areas (S. Cahill and Llimona, unpublished data), given that existing continuous fragments of habitat are not large enough to fulfil all of their requirements. Peak times for wild boar movements in the park (Cahill *et al.*,2003) also coincide with hours of highest traffic intensity, increasing the risk of collisions with vehicles.

On the other hand, less abundant species, especially carnivores such as the genet (*Genetta genetta*) and, above all, the badger (*Meles meles*) can become easy victims of FRCs. In Collserola, the badger is in a delicate situation due to habitat loss and transformation, and this mustelid is known to be vulnerable to FRCs and habitat fragmentation in other areas (Hicks and Peymen, 2002).

Figure 2.
Traffic intensity (daily average density) and corresponding vertebrate wildlife mortality on stretches of conventional roads in Collserola Park.

Figure 3.
Wildlife mortality on roads is an important element of the phenomenon of habitat fragmentation with significant consequences for some species. Hedgehogs are the most common victims on roads in Collserola Park.

In all cases, the proximity of a road, or railway, to wildlife habitat will have several important consequences: firstly, in Collserola it has been observed that the probability of FRCs on conventional unfenced roads increases in line with traffic intensity Figure 2). In the case of motorways and railways in Collserola, these infrastructures have perimeter fencing installed which reduce the impact of FRCs on mammals, but at the same time this feature creates an important barrier effect for this group. In both situations, the proximity of the infrastructure leads to a reduction in the quality of adjacent wildlife habitats, either because they represent a risk of FRCs, or because they block or hinder wildlife movements between habitats located on either side of the infrastructure. These situations signify varying risks and costs for the different species involved, depending on such parameters as the type of infrastructure, the type of habitat (vegetation), the spatial requirements of the species in question, etc..

As well as the direct effects of infrastructure, such as habitat loss and the transformation of adjoining habitats, there are also other additional effects, such as chemical or acoustic pollution, which can be particularly negative for aquatic habitats, or sensitive bird species, for example. These and other ecological effects of roads have recently been reviewed in detail (Forman *et al.*, 2003; Trocmé *et al.*, 2002).

Study area and methods

Although the study is centred on the fragmentation effects caused by infrastructure in Collserola Park (8,500 ha), the territory considered in the analysis includes a wider area of some 13,865 ha, corresponding to the area within the main ring of major infrastructures that surround the Collserola mountains (Figure 4).

The basic methodology used consists of an analysis of the current state of habitat fragmentation in Collserola due to transportation infrastructure (high capacity roads/motorways, conventional roads and railways), comparing this situation with a possible future scenario as envisaged under the General Metropolitan Plan for Barcelona (PGM). The following landscape metrics were used to quantify the state of habitat fragmentation in Collserola:

- Percentage of landscape occupied by a given habitat (PL)
- Patch density (PD)
- Mean patch size (MPS)
- Percentage of landscape occupied by core areas (PCA)
- Mean size of core areas (MSCA)

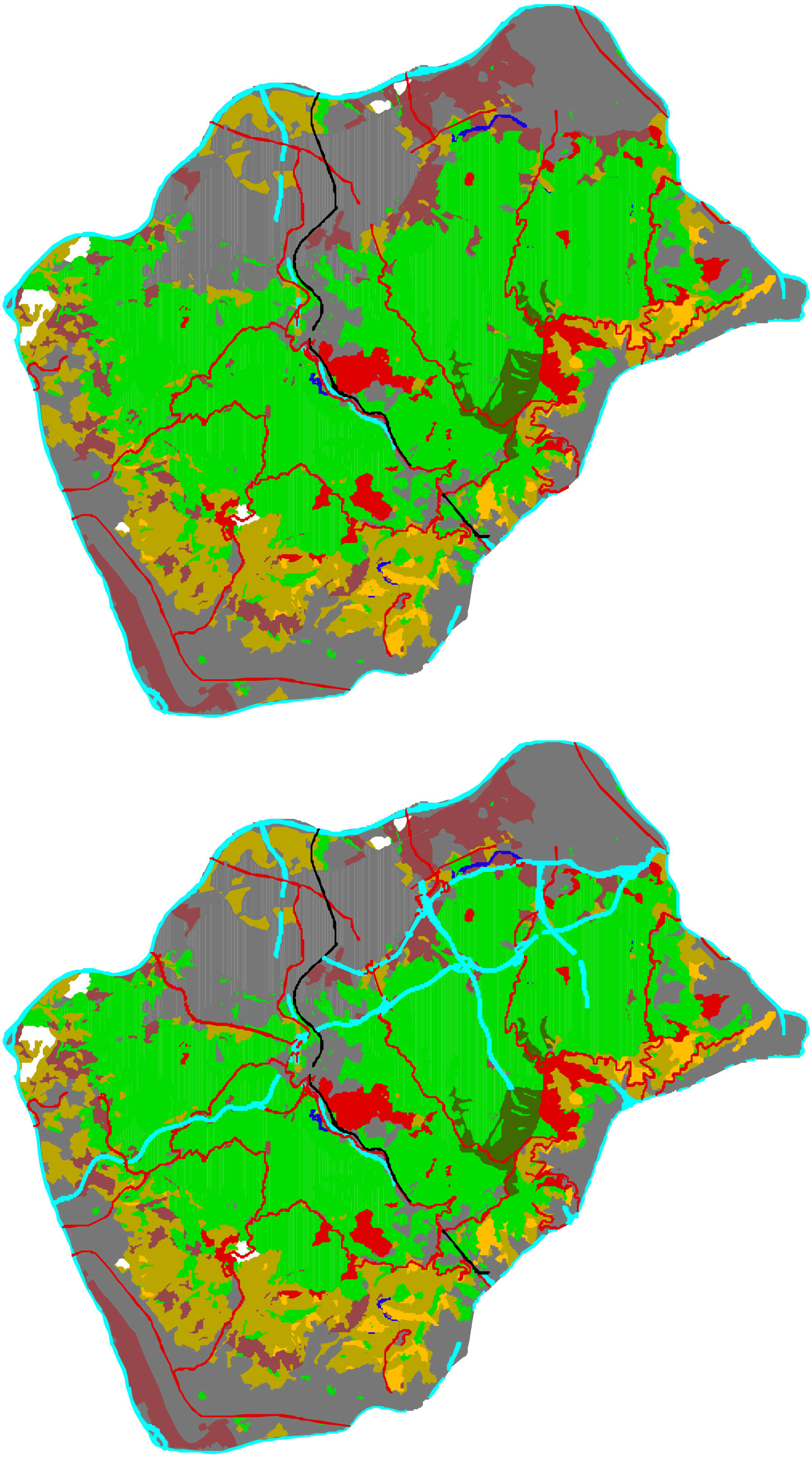
Firstly wildlife habitats in general were analysed, considering the main habitats of interest for fauna in Collserola based on their structure, vegetation and/or main land uses. The following main wildlife habitats were considered (Figure 5):

- Crops
- Grassland
- Scrub areas
- Maquia-garrigue
- Oak woodland
- Mixed woodland (pine and holm oak)
- Riparian woodland
- Rupestrian

Figure 4.
Location of Collserola Park (in green) in relation to the main transportation infrastructures (motorways/high-capacity roads in blue, conventional roads in red and railways in black) and urban areas (in grey). The study area includes the internal area defined by the continuous ring of high capacity roads that surround the Collserola mountains. The city of Barcelona is at the lower right of the figure.

Secondly, habitat fragmentation was analysed for two mammal species with differing situations in Collserola –the common genet (*Genetta genetta*) and the badger (*Meles meles*). The genet is a species with a clear preference for woodland habitats while the badger is closely tied also to other habitats such as small-scale agricultural areas with crops, riparian habitats and valley bottoms. The habitats of both of these species were classified into different quality types, considering low, medium and high quality areas. This classification was based primarily on the vegetation map of Collserola and information available on habitat use preferences in the park from previous radiotracking studies on these species (Bonet Arbolí 2003; Camps 2001). This classification facilitates interpretation of the results obtained from the analysis of the various landscape metrics used.

Figure 5.
Map of wildlife habitats in Collserola and current (upper) and possible PGM future (lower) transportation infrastructure. Agricultural areas in dark brown, grassland in orange, scrub in medium green, maquia-garrigue in dark red, oak woodland in dark green, mixed woodland in light green, riparian woodland in dark blue and rupestrian habitats in white. Urban areas in grey, motorways and high capacity roads in blue, conventional roads in red and railways in black.



The analysis of landscape metrics was carried out using FRAGSTATS 3.3 (McGarigal *et al.*, 2002). Apart from habitat types and quality classes, transportation infrastructures (roads and railways) and urban areas were included in all maps. Vector maps were first converted to 4 x 4 m cell size grids using the Spatial Analyst extension of ArcView 3.2 for posterior analysis using FRAGSTATS. Care was taken to use a sufficiently small grid cell size to avoid unwanted breaks appearing in narrow elements such as those corresponding to conventional roads. Grid maps were revised before analysis to ensure no such breaks had occurred. Distance matrices were elaborated for the analysis of core area metrics in which a given edge-effect distance was assigned to each pairwise category of possible juxtaposed land-uses/habitat types. Edge-effect distances for wildlife habitats were based on average distances indicated in previous studies on the effects of infrastructure, and in the case of specific treatments for the common genet and the badger these distances were further fine-tuned using information on spatial activity obtained from previous radiotracking studies (Bonet Arbolí 2003; Camps 2001). It should be stated that edge-effect distances can vary widely depending on the type of habitat and infrastructure considered and above all on the species under consideration, and quantitative studies on these distances are scarce (Forman *et al.*, 2003). Nevertheless, the main interest of the present study is the comparison of two different scenarios (existing and future), and in this regard absolute values of core area are of less importance in final interpretations than the proportional changes occurring between the current and future scenarios, given that edge-effect distances are maintained equal under the two situations.

Apart from the above parameters, comparisons were also made between average distances from key wildlife elements to the nearest transportation infrastructure, considering the current situation in Collserola and that of the future scenario foreseen under the PGM. Two key wildlife elements were considered in analyses –badger setts on the one hand and nest sites of two sensitive raptor species, the buzzard (*Buteo buteo*) and the goshawk (*Accipiter gentilis*). The locations of these elements are known in Collserola Park from monitoring studies that have been carried out on these species for several years. These distances are also compared with those of an array of regularly placed points (randomly located in relation to infrastructure and wildlife habitats) to examine if the location of setts of nests shows any tendency to be situated further away from roads than expected. In the case of badger setts, distances to motorways were considered on the one hand for both main setts (larger and regularly used) and outlier setts (smaller and irregularly used), and also to any badger sett location (including additional setts of known location but of unknown status). In the case of nest locations, distances to both high-capacity and conventional roads are considered in the analyses.

Results

Wildlife habitats

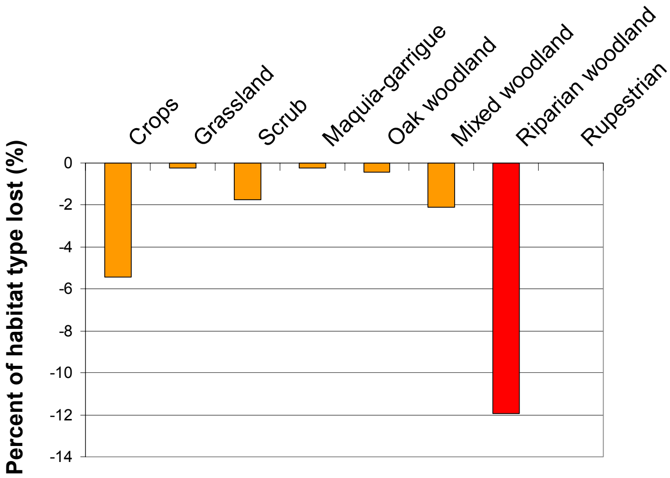
Table 1 summarises the results of the comparative analysis of fragmentation parameters for wildlife habitats under the current and PGM scenarios. Considering firstly the direct loss of habitat (changes in PL), when the current situation of habitat fragmentation is compared with that of the possible future PGM scenario there are no major changes in the proportion of territory occupied by the main habitat types accounting for the largest surface area, as is the case of mixed pine and holm oak woodlands, or scrub habitats (Table

Table 1.
Summary of changes in fragmentation metrics for wildlife habitats comparing their current situation in Collserola with the possible future scenario as envisaged under the General Metropolitan Plan for Barcelona (PGM). More important changes are highlighted in red.

		Habitat fragmentation metric				
Habitat type	**Scenario**	**PL**	**PD**	**MPS**	**PCA**	**MSCA**
Crops	**Current**	8.28	0.81	10.24	2.91	3.60
	PGM	7.82	1.28	6.13	1.88	1.47
	% change	-5.4	**+58.0**	**-40.2**	**-35.4**	**-59.1**
Grassland	**Current**	2.07	0.66	3.15	0.89	1.35
	PGM	2.06	0.69	3.01	0.88	1.29
	% change	-0.2	+4.4	-4.4	-0.8	-4.9
Scrub	**Current**	12.98	2.95	4.40	5.39	1.83
	PGM	12.76	3.36	3.80	5.16	1.53
	% change	-1.7	**+13.9**	**-13.8**	-4.2	**-15.9**
Maquia - garrigue	**Current**	3.10	0.84	3.71	2.18	2.61
	PGM	3.09	0.84	3.70	2.14	2.56
	% change	-0.2	0.0	-0.2	-1.8	-1.8
Oak woodland	**Current**	1.27	0.29	4.41	1.03	3.59
	PGM	1.26	0.30	4.18	1.01	3.34
	% change	-0.4	+5.0	-5.12	-2.1	-6.7
Mixed woodland	**Current**	38.38	2.29	16.73	30.88	13.46
	PGM	37.57	3.28	11.45	28.29	8.62
	% change	-2.6	**+43.1**	**-31.6**	**-8.4**	**-36.0**
Riparian woodland	**Current**	0.35	0.12	3.03	0.31	2.66
	PGM	0.31	0.42	0.74	0.20	0.48
	% change	**-11.9**	**+262.5**	**-75.7**	**-35.2**	**-82.1**
Rupestrian	**Current**	0.68	0.08	8.56	0.23	2.89
	PGM	0.68	0.08	8.56	0.23	2.89
	% change	0.0	0.0	0.0	0.0	0.0

Metrics: PL – percentage landscape occupied (%); PD – patch density (per km^2); MPS – mean patch size (ha); PCA – percentage core area (%); MSCA – mean size of core areas (ha). Total landscape area considered is 13,865 ha.

Figure 6.
Percentage loss of different habitat types in Collserola as envisaged by possible future development of transportation infrastructure under the General Metropolitan Plan for Barcelona (PGM).



1). However, more important changes are observed in scarcer habitats such as in agricultural areas and, above all, in the case of riparian woodland where habitat loss is as high as almost 12% under the PGM scenario (Table 1 and Figure 6). Nevertheless, when other fragmentation parameters are examined, the changes that would be produced in Collserola under the PGM are much more important, not only in the case of the afore-mentioned scarcer habitat types, but also in the case of the more well represented habitats such as mixed pine and holm oak woodlands and scrub habitats (Table 1).

In the case of mixed woodlands, for example, patch density (PD) would be increased by up to 43% under the future PGM scenario, and this same parameter would increase by 262% in riparian habitat. Similar results are obtained regarding mean patch size (MPS), for which the most important reductions are also observed in riparian and agricultural habitats, as well as mixed pine and holm oak woodlands, where MPS is reduced by 76%, 40% and 32% respectively (Table 1).

With regard to the surface area of core area habitat, it should first be stated that this is very low in certain habitat types, such as rupestrian or riparian in which it does not reach 50 ha, or in grassland with only 123 ha. These values are obviously much lower than the surface area of core area in the main habitat type in Collserola -mixed pine and holm oak woodlands- with a total of 4,282 ha of core area habitat. In this sense, the habitat types with the lowest amount of core area must be considered as those which are especially vulnerable to any perturbations that may occur in nearby areas. Proportionally, the most important losses in core area habitat would be produced under the PGM scenario in riparian habitat, crop areas and mixed woodlands, with reductions of 35%, 35% and 8% respectively (Table 1). In the case of the mean size of core areas (MSCA), the reductions are even greater, being 82%, 59% and 36% in these same three habitats.

Genet habitat

The results of the analysis of habitat fragmentation in the case of the common genet in Collserola are summarised in table 2, considering habitat quality types (high, medium and low) under the current infrastructure

Table 2.
Summary of changes in fragmentation metrics for genet habitat quality types comparing their current situation in Collserola with the possible future scenario as envisaged under the General Metropolitan Plan for Barcelona (PGM). More important changes are highlighted in red.

Common genet (*Genetta genetta*) habitat fragmentation metrics						
Scenario	**Habitat quality**	**PL**	**PD**	**MPS**	**PCA**	**MSCA**
Current	**High**	40.0	2.1	18.9	18.3	8.6
	Medium	16.1	3.4	4.8	4.7	1.4
	Low	11.0	1.4	7.8	3.4	2.4
PGM	**High**	39.2	3.0	13.3	10.2	3.4
	Medium	15.9	3.8	4.2	4.4	1.2
	Low	10.6	1.9	5.5	2.5	1.3
% change	**High**	-2.1	**+39.1**	**-29.6**	**-44.3**	**-60.0**
	Medium	-1.4	+12.2	-12.1	-5.5	-15.8
	Low	-4.1	+35.4	-29.2	-26.7	-45.9

Metrics: PL – percentage landscape occupied (%); PD – patch density (per km^2); MPS – mean patch size (ha); PCA – percentage core area (%); MSCA – mean size of core areas (ha). Total landscape area considered is 13,865 ha.

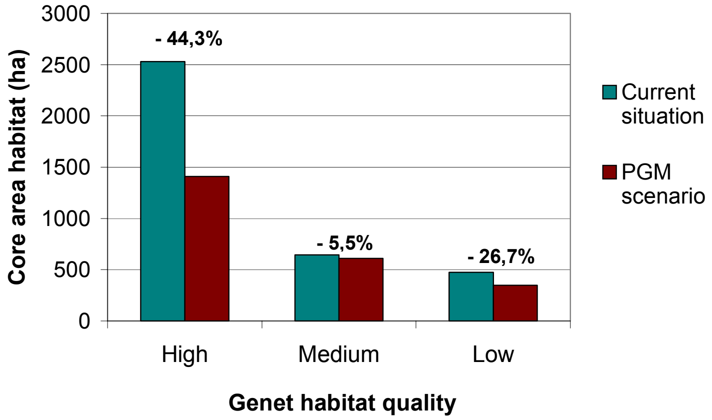
situation and that envisaged under the PGM scenario. The current landscape of the genet in Collserola is composed of 40% high quality habitat, 18% medium quality and 11% low quality habitat, while the remainder of the territory considered in the current analysis includes some 30% of urban areas and 2.5% is occupied by roads and railways. It is important to underline the fact that these proportions do not change to a very great extent under the PGM scenario, with reductions of 4.1%, 2.1% and 1.4% in low, high and medium quality habitats respectively (Table 2).

However, much larger changes are observed in other fragmentation metrics, the highest values being registered in all cases in high quality habitats (Table 2). In the case of high quality habitat, patch density (PD) would be increased by 39% by the development of new roads planned under the PGM, while mean patch size (MPS) would be reduced by almost 30% (Table 2). With regard to core area habitat, the proportion of landscape occupied by high quality genet habitat in Collserola would be reduced by over 44% under the PGM scenario, while the mean size of core areas would be reduced by up to 60% (Table 2).

It should be underlined that the most important changes are observed in high quality genet habitat, which accounts for most surface area in Collserola. This situation is particularly negative for the species in absolute terms of hectares of high quality habitat affected. For example, the surface area of high quality core area habitat would be reduced from more than 2,500 ha at present to less than 1,500 ha with the development of the PGM (Figure 7).

The changes observed between the current and future PGM scenario also register high values in the case of genet habitat of low quality, with reductions of almost 46% in the mean size of core areas, for example (Table 2). The least important changes were registered in medium quality habitats.

Figure 7.
Comparison of the surface area of core area habitat of different quality (high, medium and low) in the case of the common genet (*Genetta genetta*) in Collserola according to the current road and rail network and that proposed by the General Metropolitan Plan for Barcelona (PGM).



Badger habitat

Table 3 summarises the results of the analysis of habitat fragmentation in the case of the badger (*Meles meles*) in Collserola, considering landscape metrics for three categories of habitat quality (high, medium and low) under the current and future (PGM) infrastructure scenarios. It should first be underlined that medium quality habitat accounts for a much higher proportion (48.2%) of territory in Collserola than high quality (16.4%) and low quality habitat (3.5%). 29.4% of the current landscape is occupied by urban areas and 2.5% by infrastructure. Direct loss of habitat is not the most noteworthy impact under the future PGM infrastructure scenario, and although it is proportionally higher in the best quality habitats (Table 3), in absolute terms the greatest reduction of habitat would be produced in medium quality habitats, with a reduction of 115 ha against 107 ha in high quality habitat. Habitat loss in low quality habitat would only amount to one hectare.

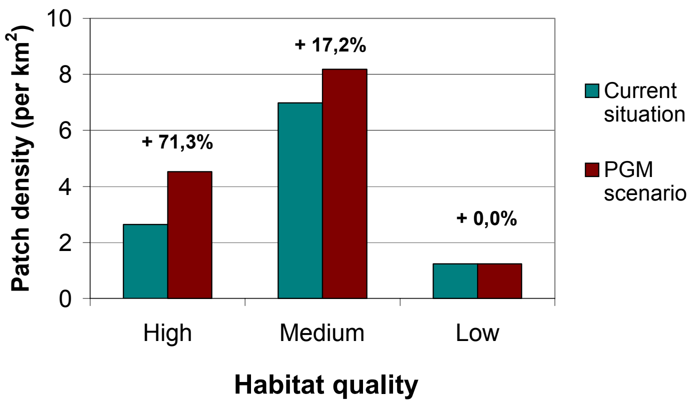
The most important changes registered among the other fragmentation metrics analysed are also concentrated in high quality habitats (Table 3),as was found for the genet, in spite of the fact that in the case of the badger these habitats occupy a much smaller proportion of the landscape (Tables 2 and 3). The 71% increase in patch density in high quality badger habitat is especially noteworthy (Figure 8), as is the 44% reduction in the mean size of high quality habitat patches. With regard to core area metrics, reductions of 28% and 26% would be produced in the proportion of core area in medium and high quality habitat respectively, this reduction being particularly important in absolute terms in the case of medium quality habitat due to the greater surface area which this category occupies in Collserola (Table 3). The mean size of core areas in high quality badger habitat would be reduced by 57% under the PGM scenario and by 38% in medium quality habitat.

Table 3.
Summary of changes in fragmentation metrics for badger habitat quality types comparing their current situation in Collserola with the possible future scenario as envisaged under the General Metropolitan Plan for Barcelona (PGM). More important changes are highlighted in red.

Badger (*Meles meles*) habitat fragmentation metrics						
Scenario	**Habitat quality**	**PL**	**PD**	**MPS**	**PCA**	**MSCA**
Current	**High**	16.4	2.6	6.2	7.5	2.9
	Medium	48.2	7.0	6.9	23.7	3.4
	Low	3.5	1.2	2.8	1.6	1.3
PGM	**High**	15.7	4.5	3.5	5.6	1.2
	Medium	47.4	8.2	5.8	17.2	2.1
	Low	3.5	1.2	2.8	1.5	1.2
% change	**High**	**-4.7**	**+71.3**	**-44.4**	-26.2	**-56.9**
	Medium	-1.7	+17.2	-16.1	**-27.6**	-38.2
	Low	-0.2	0.0	-0.2	-6.0	-6.0

Metrics: PL – percentage landscape occupied (%); PD – patch density (per km^2); MPS – mean patch size (ha); PCA – percentage core area (%); MSCA – mean size of core areas (ha). Total landscape area considered is 13,865 ha.

Figure 8.



Changes in patch density of badger habitat in Collserola under the PGM scenario.

Distance analysis

Refuge and breeding sites can represent key elements of wildlife habitat, and their optimal location is often tied to factors and concrete conditions that are not always produced at any given point in the landscape, but rather they tend to be scarce in comparison to other vital resources. Badger setts, for example, are often used during many decades, and their location can depend on such factors as soil type, slope, the presence of vegetation cover, access to feeding areas, etc.. In Collserola they are often situated at valley bottoms, and not all habitat areas are suitable for locating main setts. In the case of raptor nests, tranquillity and the absence of disturbance caused by people are of utmost importance, but others such as microclimate or the presence of large trees can also be crucial. The same nest can be used over years, or at least the same concrete nesting site can remain constant within the same territory over many years. In this sense, such fauna elements have to be considered as especially sensitive to new perturbations that may arise because the capacity of the species involved to adapt and respond is quite limited given the ties to a more or less fixed site within their territory.

Badger setts

Figure 9 summarises the comparisons of distances between badger setts and the nearest high-capacity road for the current and future PGM scenarios, as well as the comparison with the distances corresponding to a regular array of points. It can be observed that the most important reduction in distances is registered in the case of main setts, for which the mean distance to the nearest high-capacity road would be reduced by some 51% from the current 1,667 m to only 810 m under the PGM scenario. The reduction in mean distances are lower, but also important, in the case of outlier setts (-36%) and also when all known sett locations are considered (-39%), going from 1,250 m to 797 m and from 1,381 m to 830 m respectively in these two cases. Under the current situation, no major differences were observed between the distances from outlier setts to infrastructure (1,250 m) in comparison with expected distances (1,336 m), as was the case when all setts were considered (1,381 m). However, main setts did show a tendency to be situated on average some 331 m further away from motorways than would be expected (Figure 9). With regard to this, it should be mentioned that under the PGM scenario distances between badger setts and motorways would be reduced to similar mean distances of close to 800 m (main setts: 810 m; outlier setts: 797 m; all setts: 830 m). This distance is very similar to that which would be expected by chance (757 m) under the future PGM situation and, as such, the existing observed differential between main sett distances and expected distances would largely be eliminated.

Raptor nest locations

Figure 10 summarises the results of the calculations of mean distances between raptor -buzzard and goshawk- nest locations in Collserola and the nearest transport infrastructure (conventional and high-capacity roads). The observed mean distance between nest locations and the nearest road (any road) is, under the current situation, considerably greater than would be expected (336 m), both for buzzards (752 m) and for goshawks (587 m). With regard to the PGM scenario, the most important reductions in distances to roads are registered in the case of the buzzard (-30%) for which the mean distance would be reduced from 752 m to 525 m. In the case of the goshawk, the corresponding reduction would lower (-12%), passing from the current value of 587 m to 517 m with the development of new roads under the PGM. However, when the data are analysed for conventional and high-capacity roads separately, some observed reductions are much more important, especially with regard to the mean distance from goshawk nest sites to the nearest high-capacity road (-64%) (Figure 11). The mean distance for this species would be reduced from the current value of 2,218 m to only 799 m under the PGM scenario. In the case of conventional roads, there are no observed changes between current and future PGM distances to goshawk nest locations (587 m), and distances show little difference with regard to expected mean values (562 m). In the case of the buzzard, distance reductions are also much more important in the case of high-capacity roads (-51%), but unlike the situation of the goshawk, reductions would also be produced regarding distances to conventional roads (-27%) (Figure 12). In the case of the buzzard, the mean distance between nest sites and high-capacity roads would be reduced from 1,691 m to just 833 m under the PGM scenario, while the mean distance to conventional roads would pass from its current 823 m to 602 m in the possible future situation in Collserola.

Figure 9.
Summary of comparisons of mean distances between badger setts and the nearest motorway (high-capacity road) under the current and PGM scenarios in Collserola. N all setts = 119, n main setts = 17, n outlier setts = 52.

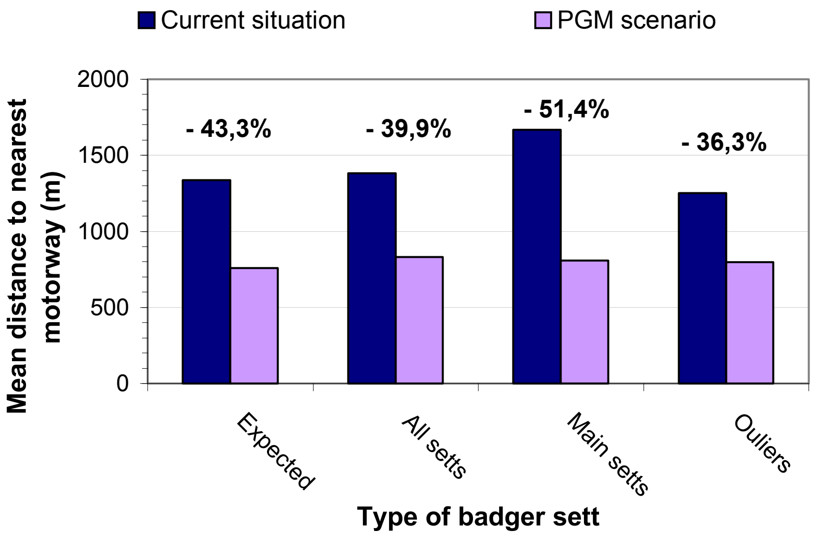


Figure 10.
Comparison between mean distances from raptor (buzzard, n=13, and goshawk, n=11) nest sites to the nearest road for the current and future PGM scenarios in Collserola.

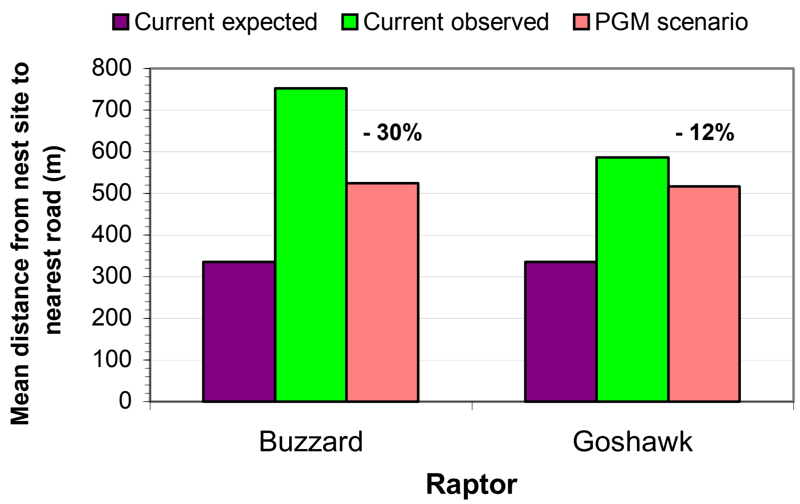


Figure 11.
Comparison between mean distances from nest sites (n=11) of goshawks (*Accipiter gentilis*) to the nearest road, according to road type, for the current and future PGM scenarios in Collserola.

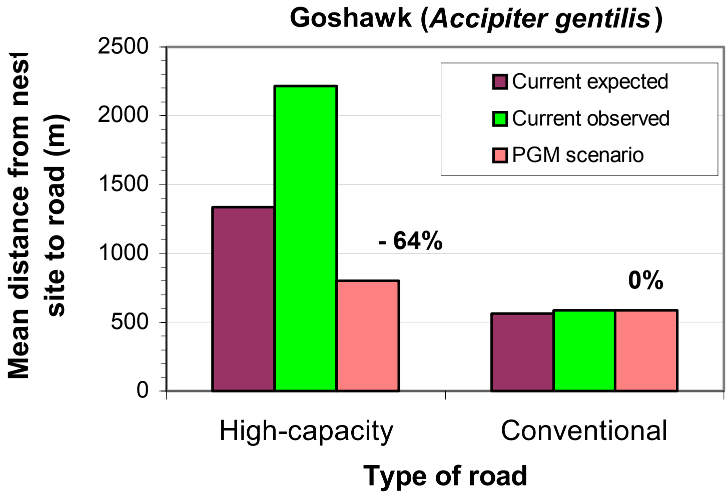
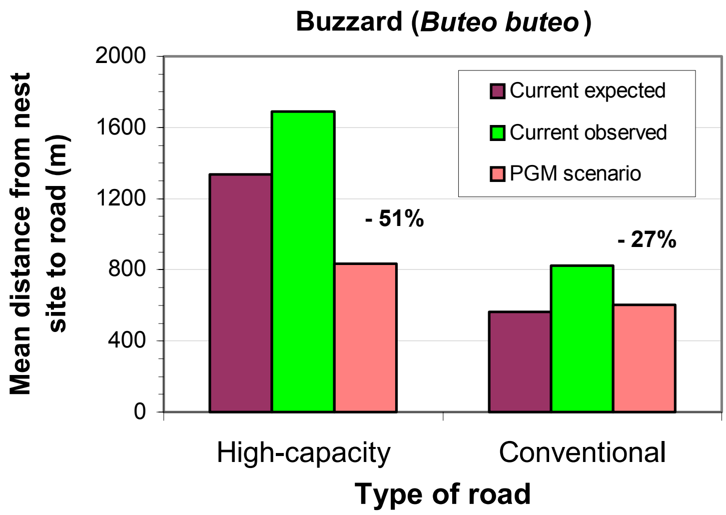


Figure 12.
Comparison between mean distances from nest sites (n=13) of buzzards (*Buteo buteo*) to the nearest road, according to road type, for the current and future PGM scenarios in Collserola.



Discussion

In the present study in Collserola Park it was observed that the direct loss of wildlife habitat due to the development of infrastructures envisaged under the General Metropolitan Plan for Barcelona (PGM) would be relatively minor in proportion to the total amount of habitat available, especially in the case of habitats occupying a relatively large surface area such as mixed pine and holm oak woodlands. This situation reflects one of the main characteristics of the impact on habitat originated by infrastructure development, that is a relatively low proportion of direct loss at broader scales (Seiler, 2002). However, at more local scales, or in the case of rarer habitats, direct loss can be of greater concern (Seiler, 2002). In the case of Collserola, , the proportional loss of scarcer habitats such as riparian woodland and crops was indeed considerable. With regard to the loss of riparian habitat, this is largely associated with one of the main infrastructures contemplated in the PGM, the so-called ridge road, which would run through the park in a general east-west direction and which would run close to an important stream along part of its trajectory. Also, other PGM roads running north-south are also contemplated as following stream and valley bottoms in much of their open stretches.

The construction of the existing motorway which currently crosses the middle of the park did in fact represent a considerable loss and fragmentation of riparian habitat, and more than one kilometre of stream now runs through a tunnel directly beneath this motorway. In this case, its design has been particularly negative with regard to permeability for wildlife across the road, as there are the typical drainage underpasses which would usually cross such roads in a transverse manner are almost non-existent, given that drains are simply channelled directly into the stream tunnel under the motorway.

Apart from direct habitat loss, linear transport infrastructure generates a proportionally large area of edge effect in relation to the surface area that they actually occupy, much greater than that which would be produced by a similar surface area of urban ground concentrated in a single block, for example (Forman *et al.*, 2003). Fragmentation impacts, usually not considered in impact assessments, can be considerably more important than direct habitat loss. In the case of Collserola, there were very considerable changes in the various fragmentation parameters considered when comparing the current and future PGM scenarios and, unfortunately, most of the most severe impacts would be concentrated in the higher quality habitats analysed (case studies of badger and common genet).

Some of the most important changes observed in fragmentation parameters analysed in the present study were registered in core area metrics. Alongside a road or railway there exists an affected area whose width varies in accordance with parameters such as the type of infrastructure involved, traffic levels, habitat type and structure, etc. The presence of such a road-effect zone is well known and documented, although in many instances the distance it extends away from the infrastructure can vary widely depending on the particular case (Forman, 2000; Forman *et al.*, 1997; Forman *et al.*, 2003). Beyond this area of influence, it can be considered that the remaining core area habitat is largely unaffected. One of the most negative consequences of the phenomenon of habitat fragmentation caused by transportation infrastructure is the fact that, as the density of the road and rail network increases the corresponding proportion of core area is reduced at an alarming rate (Seiler, 2002). This effect is not always obvious, especially when information is lacking on the width of affected areas beside roads, and as such it is often not considered in the evaluation of possible impacts of new infrastructure.

The development of new roads or railways in already fragmented territory can have unexpected consequences, given that the fragmentation effects only become evident when a certain threshold of infrastructure density has already been surpassed (Seiler, 2002). The fact that such a large proportion of core area habitat could be lost under the PGM scenario would indicate a probable approximation to critical threshold levels for certain habitats in Collserola if the plan were to be developed. Again, riparian habitat and small-scale agricultural areas (crops) of important value for wildlife are those most affected by loss of core area and reduction of mean core area size. These same effects were also again concentrated especially in high quality wildlife habitats in the park. In this sense, it should be borne in mind that fragmentation impacts would be added to an already delicate existing situation where anthropogenic pressure is at quite high levels –isolation from other protected areas, increasing traffic levels, urbanisation, etc..

The most common procedure for evaluating, in general terms, the overall environmental impact of new transport infrastructure in Europe over recent years has been that of Environmental Impact Assessment (EIA Directive 97/11/CE). Although EIA should be the main tool available for helping to avoid the specific impacts also associated with habitat fragmentation caused by infrastructure, it has some serious limitations in this regard, principally because it is often applied at a late stage in the overall planning process when routes have already been largely decided, and more importantly because it focuses on single projects, and sometimes even on sub-projects (Piepers *et al.*, 2002). As such there is no overall vision with regard to the full fragmentation effects of the completed network. A project by project approach to assessing habitat fragmentation simply does not allow for an appreciation of the combined effects, and too often the individual impacts associated with single roads will be deemed as not being critical. In others, impacts may be reduced through the application of appropriate mitigation measures. Nevertheless, a global vision of the impact of plans is required. The more recent EU Directive 2001/42/CE on the Evaluation of the Effects of certain

Plans and Programs on the Environment (Strategic Environmental Assessment SEA, see Oñate *et al.*, 2002) should represent an important step forward in allowing for an improvement of habitat fragmentation caused by infrastructure. In this new impact assessment framework, the application of landscape ecology based methodologies, and indeed road ecology principles, will play an increasingly important role (Burel & Baudry, 2002; Forman et al., 2003), in which landscape metrics represent invaluable quantitative tools (Botequilha Leitão and Ahern, 2002). Proximity to infrastructure has also been used as a quantitative parameter in SEA procedure (EEA, 1998).

In summary, the availability of abundant home grown data on wildlife requirements and habitat use in Collserola has facilitated a fragmentation-based approach illustrating certain important, but all too often hidden, effects of infrastructure development, and at the same time, we feel, gives credence to the results obtained. In the present study we have endeavoured to undertake an assessment, using an SEA-type approach, of the habitat fragmentation impacts that might arise in Collserola Park as a result of the possible future development of transport infrastructure envisaged in a specific territorial planning scenario -the General Metropolitan Plan for Barcelona-, comparing the current and final situations. Using a reduced set of landscape metrics we have shown important possible fragmentation impacts, both at the general wildlife habitat level and for specific case studies. In combination with the quantitative assessment applied using landscape metrics, distance (proximity) analyses in relation to key wildlife elements in the park -badger setts and raptor nests- have also shown major changes that could arise under the PGM scenario in Collserola.

Acknowledgements

Our thanks go to Jordi Sánchez for his assistance with computer logistics, to David Camps for his work in Collserola Park on the common genet, and to Professor José Domingo Rodríguez Teijeiro of the Faculty of Biology of the University of Barcelona for his interest and encouragement in our work. Finally thanks to all our colleagues at the Can Balasc Biological Station.

References

Bonet Arbolí, V. (2003). Ecoetologia del toixó (*Meles meles* L.) en ambients mediterranis. Behavioural ecology of the badger (*Meles meles*, L.) in Mediterranean environments. Ph.D Thesis, University of Barcelona.

Botequilha Leitão, A. & Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. Landscape and Urban Planning 59: 65-93

Burel, F. & Baudry, J. (2002). Ecología del paisaje. Ediciones Mundi-Prensa, Madrid. Pp. 353.

Cahill, S., Llimona, F. & Gràcia, J. (2003). Spacing and nocturnal activity of wild boar *Sus scrofa* in a Mediterranean metropolitan park. Wildlife Biology 9, Suppl. 1: 3-13.

Camps, D. (2001). Estudi amb radiotracking de la geneta (*Genetta genetta*) al Parc de Collserola. Memòria final de resultants. Unpublished report. Consorci del Parc de Collserola. Pp. 94.

EEA (1998). Spatial and ecological assessment of the TEN: demonstration of the indicators and GIS methods. European Environment Agency. Copenhagen, Denmark. Pp. 52.

Forman, R.T.T. (2000). Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14: 31-35.

Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S., & Alexander, L.E. (1997). Ecological effects of roads: Towards three summary indices and an overview for North America. In: Canters, K., Piepers, A. & Hendriks-Heersma, A. (Eds.) Proceedings of the international conference on 'habitat fragmentation, infrastructure and the role of ecological engineering'. Maastricht and the Hague 1995. pp. 40-54. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering Division.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T. & Winter, T.C. (2003). Road Ecology: science and solutions. Island Press, Washington, Covelo & London. Pp. 481.

Forman, R.T.T. & Godron, M. (1986). Landscape Ecology. John Wiley, New York.

Hicks, C. & Peymen, J. (2002). Habitat Fragmentation due to Existing Transportation Infrastructure. In: Trocmé, M., Cahill, S., De Vries, J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. & Peymen, J. (Eds.) COST 341 – Habitat fragmentation due to transportation infrastructure: The European Review, pp. 73-113. Office for Official Publications of the European Communities, Luxembourg.

Marull, J. & Mallarach, J.M. (2002). La conectividad ecològica en el Área Metropolitana de Barcelona. Ecosistemas 2002/2 (URL: http://www.aeet.org/ecosistemas/022/investigación6.htm)

McGarigal, K., Cushman, S.A., Neel, M.C. and Ene, E. (2002). FRAGSTATS: Spatial Pattern Analysis Program for Categorial Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: www.umass.edu./landeco/research/fragstats/fragstats.html

Oñate, J.J., Pereira, D., Suárez, F., Rodríguez, J.J. & Cachón, J. (2002). Evaluación Ambiental Estratégica. La Evaluación Ambiental de Políticas, Planes y Programas. Ediciones Mundi Prensa, Madrid. Pp. 382.

Piepers, A., Álvarez, G., Bouwma, I.M., De Vries, H.(J.G.) & Seiler, A. (2002). Minimising Fragmentation through Appropriate Planning. In: Trocmé, M., Cahill, S., De Vries, J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. & Peymen, J. (Eds.) *COST 341 – Habitat fragmentation due to transportation infrastructure: The European Review,* pp. 31-50. Office for Official Publications of the European Communities, Luxembourg.

Pino, J. I Rodà, F. (1999) L'ecologia del paisatge: un nou marc de treball per a la ciència de la conservació. Butll. Inst. Cat. Hist. Nat., 67: 5-20.

Rosell, C., Álvarez, G., Cahill, S., Campeny, R., Rodríguez, A. & Seiler, A. (2003). COST 341. La fragmentación del hábitat en relación con las infraestructuras de transporte en España. O.A. Parques Nacionales. Ministerio de Medio Ambiente, Madrid. Pp. 349.

Seiler, A. (2002). Effects of Infrastructure on Nature. In: Trocmé, M., Cahill, S., De Vries, J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. & Peymen, J. (Eds.) COST 341 – Habitat fragmentation due to transportation infrastructure: The European Review, pp. 31-50. Office for Official Publications of the European Communities, Luxembourg.

Tenés, A., Cahill, S. & Llimona, F. (2003). Atropellament de fauna a les *carreteres del Parc de* Collserola: una primera aproximació. Informe inèdit, Estació Biològica de Can Balasc, Consorci del Parc de Collserola.

Trocmé, M., Cahill, S., De Vries, J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. & Peymen, J. (Eds.) (2002). COST 341 – Habitat fragmentation due to transportation infrastructure: The European Review. Office for Official Publications of the European Communities, Luxembourg. Pp. 251.