4. TERRITORY'S CONNECTIVITY AND ECOLOGICAL CORRIDORS

The basic premise of landscape ecology is that there is a close relation between the landscape's spatial configuration and the processes taking place in it, in the understanding that spatial configuration not only refers to the nature of its elements (the uses the ground is put to or the types of vegetation) but also to the spatial relations of vicinity, proximity, shape, etcetera, established among them (Forman, 1990; Wiens et al, 1993).

In this chapter the scientific bases are summarised as provided by landscape ecology particularly related to the territory's connectivity, putting a special emphasis on the role of the landscape's heterogeneousness and in the ecological corridors as territorial structures whose integration into the design of a coherent conservation network is basic, due to their contribution to connectivity.

4.1. The preservation of ecological processes in a conservation network

The objectives of nature conservation policies have evolved over the last few decades, from the emphasis put on the protection of emblematic species, unique landscapes, biodiversity and species habitats, to the latest tendencies towards the conservation of ecological processes and that of those processes concerning the operation of the landscape (Noss, 1993, Franklin, 1993, Regier, 1993; Nott and Pimm, 1997, Montes, 1995). The is not only to conserve the wealth of species, but also to maintain their natural dynamics in a sustainable manner (Knuffer, 1995), including the conservation of their habitats and the ecological processes they require for their survival. The conservation networks aim at the conservation not only of unique elements, but also of the whole of the ecological processes in operation in the landscape, as well as the whole of the environmental goods and services.

The flows of matter, energy and information which take place in the landscape may be due to physical factors (wind, water streams), or to the animals' own mobility (not to mention the flows directly due to human action). Occasionally the flows come about in a vague manner (e.g. the wind), either from all directions or by following an environmental gradient. Table 4.1 shows a possible classification and a brief description of the main ecological flows whose preservation must be an objective of the conservation network.

Table 4.1. Main flows found in the landscape and their relation to the keeping of the functions of the ecosystems.

Type of flow (motive power)			Transported elements	Functions of the ecosystems
Physical Factors	Aeolian flows (wind)		Gases, dust particles, spores, seeds, micro-organisms	• Maintenance of air quality, weather regulation • Pollination of anemophilous plants, and for all species which during its lifecycle have adaptations to the dispersal through the wind (anemochore), either in the form of eggs (e.g.; certain crustaceans) or else in the form of spores or plant seeds. • Maintenance of geomorphologic processes (dunes)
Physical Factors	Hydrological flows (water streams)	Underground waters	Water, minerals	• Maintenance of water sheets in wetlands • Maintenance of flow volumes in rivers and brooks • Maintenance of the quality of water • Microclimate regulation • Water reservoir
Physical Factors	Hydrological flows (water streams)	Surface waters	Water, minerals, nutrients, organic matter, spores, eggs, seeds, micro-organisms	• Habitat for water and hygrophilous species and communities • Dispersal of species adapted to being dispersed through water streams (hydrochory). • Maintenance of the quality of water • Availability of nutrients, productivity control (eutrophy / oligotrophy) • Microclimate regulation • Geomorphologic erosion processes (runoff), transport (rivers) and sedimentation (alluvial plains, deltas) • Maintenance of the coastal systems geomorphology
Mobility of animals			Animals, water, minerals, nutrients, organic matter, spores, eggs, seeds, micro-organisms	• The movements of the fauna (on their on power) are due to the requirements of feeding, to climatic ones, (temperature and humidity gradients), to the search after a territory of their own, to reproduction, to running away from fires, etcetera • The movements between different points within a habitat of the same type (between forest patches or between wet zones) make it possible to obtain all the resources needed by an individual. They prevent the isolation of populations as well as endogamy and genetic drift problems. • The movements between different ecosystems enable the animals to look for complementary environments for their survival. Seasonal movements may follow a North - South latitudinal gradient (e.g. birds over - wintering in the Iberian Peninsula). Local migrations may be altitudinal in character, occupying the highest areas during the summer and getting down from them in winter. Thanks to the movements between terrestrial and aquatic ecosystems, many terrestrial species find refuge in the hottest time of the year and many species associated with the aquatic systems use the terrestrial habitats to feed, etcetera. There are also movements between the highlands, forests, grazing lands... between natural and man-made ecosystems (farmlands, gardens, dumping sites), etcetera

Ecological flows may be reduced or favoured by the structures existing in the landscape. Ecological corridors and **stepping stones** are structures which facilitate the territory's connectivity. The concepts contributed by landscape ecology such as fragmentation, connectivity, barrier, corridor, are very useful in defining a conservation network.

Barriers can be created by the operation and natural structure of the landscape (e.g. mountain alignments or big rivers), or as a result of human influence (e.g. intensive agriculture or roads). In the latter case, the barriers bring about the interruption of ecological flows due to the break-up of the habitat's continuity, which creates the fragmentation of the landscape.

The landscape's connectivity is a more general term which incorporates the concepts of corridor and barrier, and indicates how the ecological flows respond to the structure of the landscape (Noss, 1993). This relation depends on the landscape's physical or structural aspects, as well as on the characteristics of the ecological flow and the size, the behaviour and the mobility of the very animals (Taylor et al, 1993).

The connectivity of the landscape within an ecological network is defined by the capability to maintain the ecological flows and the connections linking the different areas or elements in the network. The connectivity does favour the flows of energy and matter which are key to the operation of ecosystems; among them, the migratory movements, the dispersal movements, the pollination, the flows of nutrients, etcetera. The connectivity of a network would facilitate the response capability of landscapes and species when faced with political and economic uncertainty, or with climatic change (Hill, 1995).

The connectivity depends on the spatial structure of the landscape and on the permeability of the different components that make it up. The core areas constitute the sources of dispersal and the rest of the landscape's components will increase or diminish the flows of matter and energy through the landscape. The connectivity between two core areas will depend, in the main, on three properties of the landscape: the mosaic's permeability, the existence of ecological corridors and the existence of stepping stones (Fig. 4.1) (Bennet, 1998).

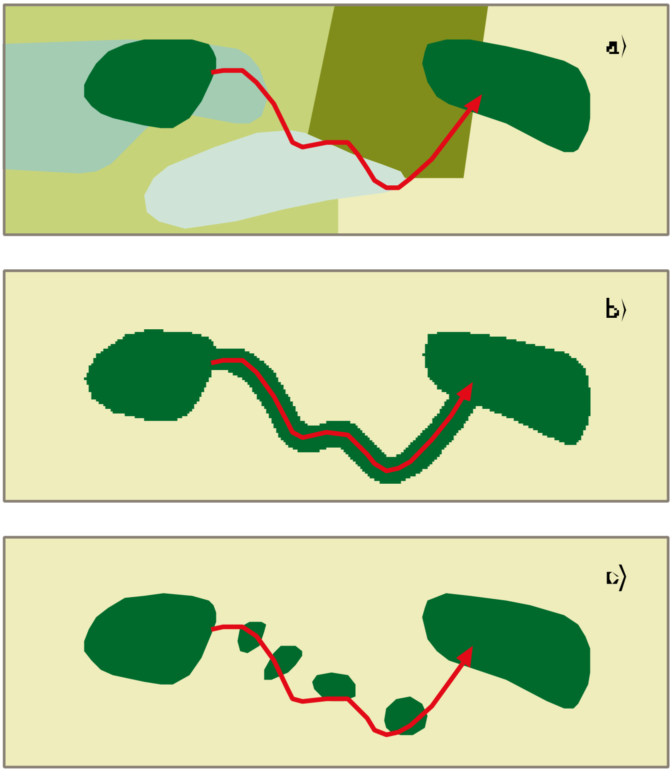

Figure 4.1. The permeability of the landscape can be enhanced (a) by maintaining the whole of the mosaic between two source areas or (b, c) by maintaining certain elements of the landscape which allow the dispersal of certain species. These dispersal elements can be unbroken (b) or discontinuous (c).

4.2. Permeability of the mosaic

Not only the existence and the state of preservation of the corridors, but also the spatial distribution of the patches and the characteristics of the matrix, are determining factors in the flows being established in the landscape, be they of species, matter or information, as well as in the regulation of nutrient or energy cycles.

Thus, we could talk about an optimal landscape mosaic which would guarantee the stability of the landscape and the preservation of essential processes. The best mosaic would be that which would make the conservation of the biodiversity and the processes possible, in a manner compatible with the social use of resources (Forman, 1995).

In the landscape permeability survey, the role must, therefore, be taken into account of all the elements making it up. It is important to bear in mind the types of covers (and their spatial distribution, boundaries, etcetera), as well as the different types of linear landscape elements. Not only the existing barriers or filters have to be studied (big infrastructures, dams), but also the bank corridors, the linear corridors and the plots of land kept separated by a small distance (stepping stones).

The heterogeneity of the landscape is very closely related to the conservation of the ecological processes taking place at a landscape scale and, most specially, to the distribution of the biodiversity (Pino et al, 2000; Atauri and de Lucio, 2001). This relation's intensity varies depending on the groups of animal species under examination, it being greater in those with high mobility and capability disperse, such as birds or butterflies. As a rule, the diversity of species is greater in the more heterogeneous countries, for the coexistence of different types of ground use means a greater wealth of ecosystems and enables the coexistence of groups of species which exploit different niches, which results in a bigger overall diversity (Fig. 4.2).

On the other hand, the heterogeneousness is also related to the fragmentation. Very heterogeneous landscapes with a high degree of evenness may show a high level of fragmentation, and the wealth of species may diminish as a result (Santos and Tellería, 1997). This particular aspect has been studied in the case of open - environment birds, whose greatest wealth is found in heterogeneous landscapes where the ground has been put to a large variety of different uses, but in which the fragmentation of the agrarian matrix is not excessive; in other words, in which there is a relatively low evenness (Atauri and de Lucio, 2001) (Fig. 4.2).

The heterogeneity of the landscape is also related to the maintenance of other flows at a landscape scale, such as the greatest resistance to disturbances such as fire, whose progress is made difficult in landscapes consisting of patches of different types of vegetation. The nutrient and materials cycles can be slowed down in heterogeneous agrarian landscapes, where patches with different degrees of maturity do coexist. In the patches made up of mature ecosystems the nutrient cycles are slowed down, the runoff is controlled and, therefore, so are the flows of materials as well as the hydrological flows. For their part, the exploited systems are characterised by a grater renovation rate, by faster nutrient and materials cycles and, occasionally, by a worse control of the hydrological cycles. An appropriate distribution of the patches creating mosaics of different types of ground use, in which together with exploited plots of land there would be mature ecosystem patches with a low renovation rate, does favour the accumulation of biomass and the formation of soil, the holding of nutrients and the control of the runoff, and the circulation of species through the landscape, thus guaranteeing the connectivity between distant populations.

This type of permeability based not on the existence of corridors but, rather, in a landscape mosaic making the different ecological flows possible, can be obtained under certain conditions in heterogeneous landscapes, such as the Mediterranean agrarian landscapes. The mosaics that would be capable of favouring the connectivity of the landscape would be those which have not experienced loss of natural covers but, rather, have undergone transformations thereof, as it happens in the case of the pasture lands. In these landscapes, the boundaries or limits between what has been altered or transformed are vague in the manner of alteration gradients between the natural, more unaltered, ecosystems and those having been altered.

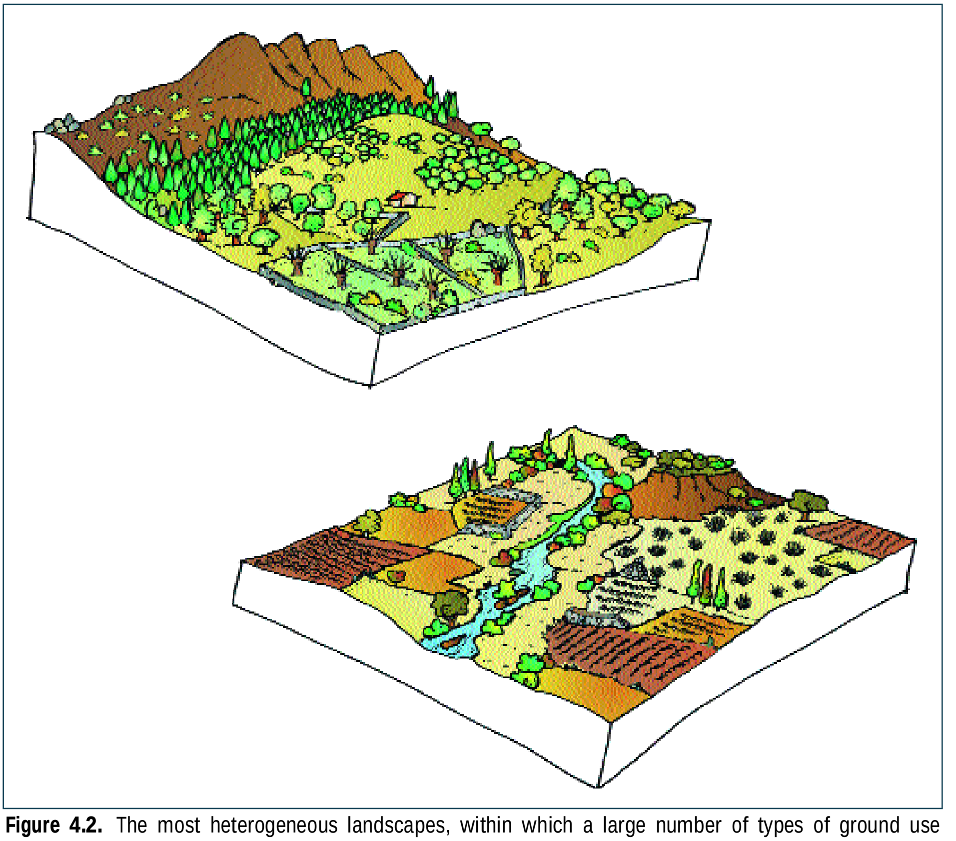

Figure 4.2. The most heterogeneous landscapes, within which a large number of types of ground use coexist, are associated with a greater wealth of species. In agrarian landscapes where one type of ground use is predominant, this landscape heterogeneity is achieved thanks to the existence of small patches put to different types of uses and incorporated into the agrarian matrix. (Illustrations by Olga Ibarmia Huete).

In the Mediterranean context, the heterogeneity of the landscape is of basic importance. This great heterogeneity is attributed both to a high degree of climatic and topographical variability and to human intervention, which has fostered a most heterogeneous mosaic of ground uses, in which a large number of patches having been subjected to different degrees of management coexist with remnants of natural vegetation (Burel and Baudry, 1995; Farina, 1997; González Bernáldez, 1991 y 1992). Landscapes characterised by a high degree of heterogeneity concerning ground uses are home to large variety of species and act as dispersal areas, by providing resources and refuge (Pino et al, 2000)

In the Mediterranean region heterogeneous landscapes can constitute “wide corridors”, in most cases alignments of mountains and basins with environmental gradients. Mountain alignments can have shapes of a more or less elongated ground plan, and may have a connective function not only for species belonging to these areas, but also for other species, due to their best state of preservation (being less exploited than lower - altitude areas).

4.3. Ecological corridors

A key feature of ecological corridors is that the intensity of the matter and energy flows is greater there than in the rest of the territory. Ecological corridors are the result of the natural operation of the landscape (e.g. water streams), or else do result from human influence (e.g. unaltered areas).

The term ecological corridor has given rise to a certain amount of controversy (Simberloff et al, 1992; McEuen, 1993; Mann and Plummer, 1995), partially due to the existing confusion between different meanings depending on the point view, be it structural, or related to the operation or management of the landscape. With a view to avoiding confusions we shall consider three types of definitions:

- Structural concept: Linear or elongated element of the landscape, being qualitatively different from the adjacent units.
- Functional concept: Preferential dispersal or migration route in which a species does find the required level of protection to carry out its movements.
- Legal or managerial concept: Natural spaces enjoying some kind of legal protection, due to their value as a linear habitat and / or to their connective

function, and having been defined with the intention of avoiding the isolation of natural protected areas.

The function of landscape elements as ecological corridors begun to be studied in depth in the early nineties (Saunders and Hobbs, 1991; Smith and Hellmund, 1993; Lindenmayer and Nix, 1993). The connective function of ecological corridors can be quantified by comparing the intensity of flows through the corridor and through the adjacent plots of land (Opdam, 1990). Thus, it is possible to graphically represent the functions of the landscape elements both as corridor and as barrier with regard to ecological flows (Fig. 4.3).

In addition to increasing connectivity, corridors are also usually valuable due to their function as habitats; the confusion between the function of habitat and that of the corridor is quite frequent. For instance, Simberloff and others (1992), or English Nature (1994), mention several examples giving evidence of the use of corridors, in which it cannot be distinguished whether the species are using the elements of the landscape only as a habitat or, in the main, as corridors for their movements.

A distinction can be drawn between the connectivity of ecological corridors in itself (as conditioned by their width, continuity, etcetera) and the connectivity between corridors and adjacent systems (Sterling, 1990; Noss, 1993). Concerning the connectivity with the adjacent plots of land, it is possible to distinguish, according to the direction of ecological flows, between the function of source and the function of drain (Fig. 4.3).

It is possible to designate as corridor any type of territorial entity, regardless of being linear or not, provided that its objective be to keeping of the connectivity of the landscape and the reduction to a minimum or the elimination of the negative effects of the structure of the landscape (fragmentation or barriers). Three basic types can be distinguished according to their origin and structure: stream corridors, line corridors and strip corridors (Knuffer, 1995; Kubes, 1996; Forman and Godron, 1986).

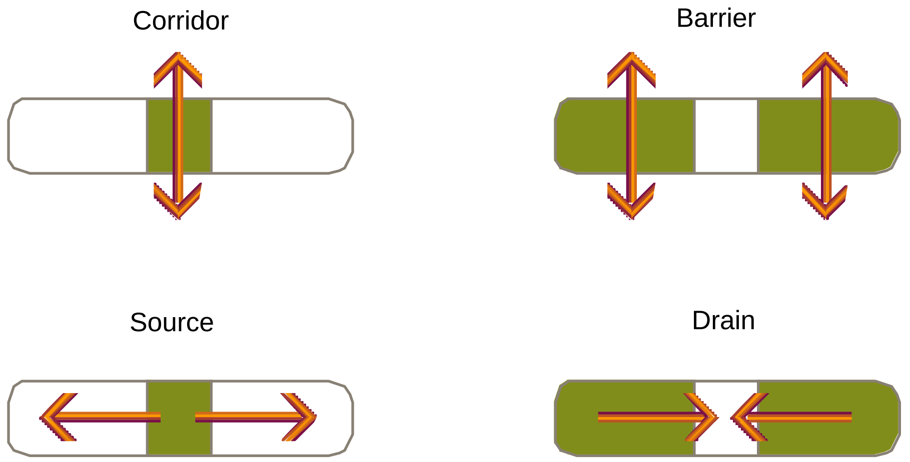

Figure 4.3. Functions of ecological corridors. The intensity of flows along the corridor and in the adjacent plots of land does determine the functions of corridor and those of barrier. The flows between the corridor and the adjacent areas generate the functions of source and drain. The ecological flows are represented in the figures with arrows. Modified from Noss (1993).

4.3.1. River and stream corridors

The importance of rivers and banks in the operation of the landscape seems to be indisputable, due both to their habitat functions and to the corridor ones, and specially so in Mediterranean environments (Montes et al, 1987; Sterling,1990). From the biogeographical standpoint, the density and the homogeneity of the spatial distribution of the banks in the territory is very important, for it determines that no area be far from some habitat of this type and, supposing that they be well preserved, they would create a system of refuges for different species.

The conservation of water ecosystems and that of the river connectivity throughout the bank corridors, is capital not only for typically aquatic animals, but also for those which find food or refuge in these habitats during the dry season, such as butterflies (Galiano et al, 1985), or for other species using rivers in their movements.

The structure and operation of the banks can enormously vary in different stretches of the same river or in different types of river. The different aspects of the spatial distribution of the river courses, as well those of their shape or space configuration may have great influence on the internal connectivity of the river (as a channel), and on the connectivity with the adjacent systems (collector in the upper basin and scatterer in the lower basin, etcetera), and because of that they are highly important for the ecological processes associated with the rivers.

In Mediterranean environments, water ecosystems are characterised by their fluctuant nature, their localised distribution, their small area and their great importance for the ecological flows (in the Mediterranean landscape, water flows are usually decisive for all other ecological flows). When large territories are being studied, it is expensive to use a highly detailed resolution scale, which is the reason why at the work scales more widely used in territorial planning, these ecosystems go unnoticed, in particular the narrowest river beds and banks. For them to be correctly identified it is necessary to use different work scales.

4.3.2. Line corridors

The hedgerows are important landscape elements due to their function as habitat and due to their possible function as corridors for woodland species. Among the species whose movements can be influenced by the existence of hedgerows, the following can be mentioned: mammals such as the squirrel, *Sciurus vulgaris* (Van Apeldoorn et al, 1994), birds (Balent and Courtiade, 1992), insects, etcetera. The distribution of some plants cal also be influenced by the structure of the hedges.

Hedgerows may also have a barrier effect against aeolian flows and on water flows, but this effect can be deemed to be beneficial for conservation. The barrier effect on aeolian flows can facilitate the flight of certain insects in windy days and the barrier effect on water flows can be a contributing factor to the prevention of erosion.

In intensive cultivation areas, any vegetation line on untilled land (hedgerows, boundaries between properties, etcetera), even if such vegetation is shrub-like or even herbaceous, may play an important role in the biological control of pests and as a refuge for wild fauna (Kemp and Barret, 1989).

Olive tree lines, typical of the Mediterranean landscape, may have similar functions to those of the hedgerows in certain cases. Olive trees provide woodland species with food and refuge, e.g. overwintering birds (Santos y Tellería, 1997). However, the single - species character, the regular structure (tree trunks of similar age, etcetera), and the management of farms probably make the number of species benefiting from it all to be smaller than it is the case in other type of hedgerows.

Stone fences can have very positive effects on the wild flora and fauna by providing them with habitat and refuge. Fences can also act as windbreaks and runoff – breaks in a similar way to the edges; they can facilitate the growth of vegetation next to them, and can even give birth to hedgerows which would cover the fence. Fences have a clear barrier effect on the movement of cattle, although such effect does not seem to be important in the case of wild fauna. Usually, fences are not high enough to prevent the fauna from crossing (due to the expensiveness of their construction), and the empty spaces between stones do facilitate the crossing or even provide refuge for small – sized species (for instance, reptiles and small mammals). As a matter of fact, the conservation and restoration of stone fences is usually recommended as an alternative to the erection of metallic fences.

Livestock ways are a special case of ecological corridor, whose main function is the movement of cattle. The structure of the livestock ways usually includes other types of linear elements, such as tracks, hedgerows, fences, rivers, etcetera. These structures can be vastly different from one stretch of the way to the other. The conservation of their structure and their use by the livestock, in connection to the extensive systems of pasture lands, grazing lands, etcetera, may determine to a great extent the role they play for wild species and for other ecological processes in general (Pineda et al. 1991a).

The function of linear elements depends to a great extent on the spatial relations with the adjacent types of cover. It is possible to develop basic models of the corridor and barrier functions of the said elements if we take into consideration the contrast with the adjacent types of cover (Lindenmayer and Nix, 1993). Several types of linear elements and several types of covers can be considered (Fig. 4.4).

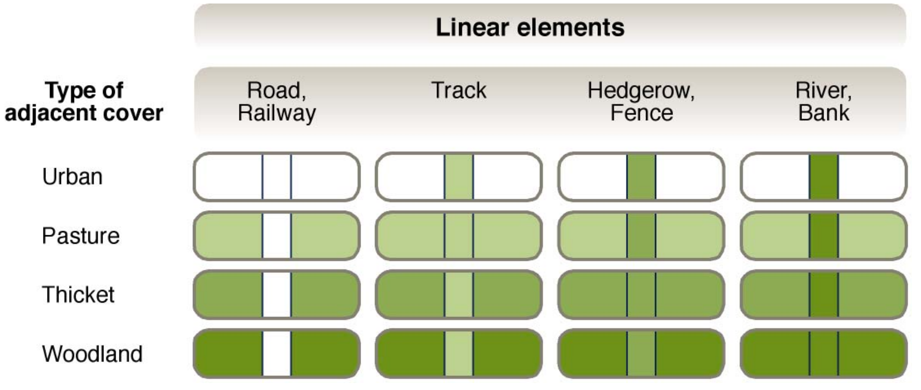

Figure 4.4. Example of the distribution of linear elements in a corridor - barrier model based on the types of adjacent cover. The structures located in the upper left part of the figure have greater potential as corridors, while those located in the lower left part have grater potential as barriers.

A linear element can also coincide with a mosaic boundary and have a different type of adjacent cover in each side, thus creating asymmetrical structures which may become very important for the flows running through the boundaries. A linear element coinciding with a boundary between two types of cover can retain its corridor or barrier function, due to the increase in the sharpness of the contrast in the boundary and to the increase in longitudinal flows, either in the corridor or in the adjacent plots of land (barrier). In certain cases, the linear element may have a buffering function, by softening the contrast between the types of covers and by catalysing the transversal flows running through the boundary (Fig. 4.5). By way if example, the lines of olive trees could have a buffering function with regard to the ecological flows in Mediterranean agrarian landscapes, for it has been noticed that such linear elements tend to be located between cereal plots and thicket areas (Sastre Olmos, 1999). The existence of several spatial relations within a landscape may benefit the species that use more than one habitat.

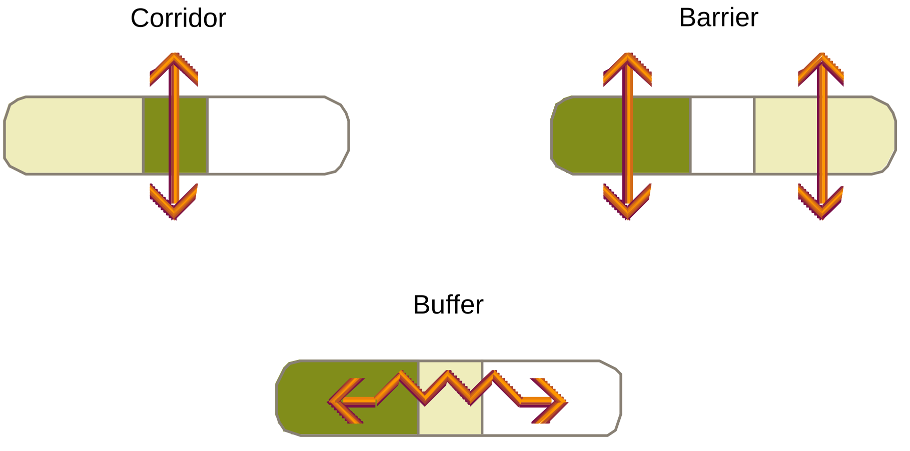

Figure 4.5. Functions of landscape linear elements coinciding with mosaic boundaries. The buffering function does soften the existing tension between the sides of the boundary.

4.4. Stepping stones

The stepping stones or broken corridors are a species of fragments of habitat separated from each other by a small distance, being so arranged that the species can make short - distance movements among these fragments and move in such a way through the landscape matrix. The stepping stones can be important for the movement of many species in the Mediterranean landscape; mainly for those which are mobile, capable of covering greater distances than those separating the fragments the stepping stones consist of.

Different types of stepping stones can be considered depending on the ecosystem (water, woodland). The pools and puddles scattered throughout the landscape operate as stepping stones for aquatic species, migratory birds, etcetera. Copses, isolated trees and scattered thicket dots do facilitate the dispersal of woodland species in open landscapes.

The definition of stepping stones must be closely related to the definition of wide corridors, for the operation of a stepping stone depends to a great extent on the matrix's state of alteration in which it is included.