CHAPTER 2

Connectivity and Protected Areas

Spatial meshes of the landscape. Concepts, applicability and urgent themes related to land planning

Francisco D. Pineda and María F. Schmitz

Introduction

It could be assumed that the territory resembles a living tissue more than an inert fabric. This idea, previously insisted upon by different authors (Glazovskaya, 1963; Solntsiev, 1974; Fortescue, 1980; Bernáldez, 1981; Pineda, 1997; Burel and Baudry 2001; Pineda *et al.,* 2002), is dealt with in this article, along with the current possibilities of applying it to nature conservation and environmental land management. The comparative terms 'tissue' and 'fabric' share the common idea of 'mesh' –that is, a structural configuration linking its components together, or facilitating this link, giving cohesion to the whole– the former and the latter having different significance and consequences.

The need exists for a suitable formalization of an idea that appears to be of great interest for nature conservation. Priorities are habitually based on emergencies, which is to some extent logical. With regard to the 'planning and ecology' relationship, there is an obvious need to protect the connections that maintain the functionality of the territorial tissue, but what remain unclear are the ecological criteria and parameters to be considered in the quantitative and pragmatic evaluation of the spatial connections which imply key environmental factors.

Having recognized the motivations and ethical convictions in applying ecological science to the plane of conservation and land management, it must be admitted that those uncertainties concerning criteria and parameters hinder the application of science on this plane. In some scientific forums, it has been considered that the coldest and most objective approach to nature conservation

Environmental Connectivity: Protected Areas in the Mediterranean Basin, García Mora, M.R. (Coord.)
© 2003, Junta de Andalucía. ISBN - 84-95785-33-1

is probably to demarcate portions of the space in which no human activity takes place (Pineda, 1991; Pineda *et al.,* 1991). This idea, along with its different variants, is used in the continual creation throughout the world of 'protected natural areas'. Therein determined laws and rules are more easily tested and applied in order to preserve generally tangible components of nature. These components are recognized as having great value according to certain criteria and points of view. It could be said that the protected areas are framework instruments of the generic idea of nature conservation and that the laws and rules are tools for its application.

The concept of conservation probably evolves as a result of the dissatisfaction caused by its related definitions and assumptions, especially in the scientific community. The idea of the ecosystem, frequently utilized with much dogmatism, is progressively being incorporated into that of conservation, to the extent that it could be said that we are not dealing with the protection of species or places, but rather with the conservation of processes of interactions, that is to say, ecosystems. At present, conservation is essentially based on two objectives: to preserve discrete portions of the space (protected areas) and to protect species and biological breeds wherever they may be encountered. The rapid changes the landscape is undergoing, however, affect the whole territory, so that there is an increasingly obvious need to add to those objectives that of maintaining key physical phenomena wherever they occur. The two former objectives seem to be easier to reach; the latter would appear to be more difficult. Furthermore, the presence of the cultural component in these three objectives is of great importance.

None of these aims, however, have convincing scientific formalization. In the protected areas, attempts to maintain 'valuable' physical or biological landscapes and components have been based on such criteria as uniqueness, rareness, usefulness and above all, ethical reasons. This type of consideration is aimed at conserving species, some of which are on 'red lists', either as threatened species or those in danger of extinction. With regard to physical phenomena, their role in conservation has attracted less attention than the species or the landscape, or at least explicitly. However, in order to environmentally plan land uses, certain vectorial phenomena that support spatially relevant ecological processes are decisive. This is the case of energy flows and movement of water and materials with a 'natural' cadence, biological migrations, etc. These processes give cohesion to the territory and facilitate the interaction between the protection of spaces and the environmental management of larger counties and regions.

Territorial tissue

Physical phenomena such as those involved in the hydrological cycle, the transport of materials downslope, percolation of the rain and recharge of aquifers, evaporation in wetlands, alteration of the rock, insolation of the substrate, heating of the air, eolic transport of materials and the dynamics of the air, seas and lakes, can occur without the participation of life. However, they connect certain portions of space with others, constituting a mesh.

The biosphere is the organic component that covers this mesh. It is supported by these phenomena in much the same way as the outer casing of the cables of an electric engine – although contributing with essential ecological properties to the whole –. Life is based on the diversion of a tiny fraction of the energy from these physical phenomena in order to produce biomass. The growth of this and its genetic, morphological and spatial diversification act upon the previously mentioned mesh, modifying the speed of the flows. This modification thus affects water flow and transport of materials, for which life can either use the same physical channels (for instance, runoff through the slopes is related to the moisture of the organic matter in the soil) or can provoke new channels (contributions of oxygen from the water to the air are due to photosynthesis). The soil formed upon the rocky substrate contains above all organic material and humus which slow down the flow of water and materials on slopes and allow the maintenance of a more uniform volume flowing in rivers. The maintenance of this type of ecological processes seems essential for the environmental management of the territory and is really the key to nature conservation. Throughout the world, continuous changes occur in land uses which affect these processes at local, regional and global levels.

Ecological processes are numerous, involving both physical and biological factors. Some of these processes originate geological materials and relieves that offer emotive and valuable landscapes. Thus mountains, valleys, coasts, etc., can be shaped, creating an emotional environment that invites people to admire, respect and attempt to conserve it. Other natural manifestations, of a biological nature, such as genetic diversification, generate unique species that society considers to be particularly worthy of protection, and sees them as emblematic, due to their beauty, size, rareness, etc., calling them by roughly formalized names, like ‘engineer’ or ‘keystone’ (without substitute) species, etc. It must not be forgotten that nature conservation should be based on processes and that the species bear witness to these.

This is the panorama in which nature is to be conserved, its resources to be exploited in a prudent way and the territory is to be environmentally managed. In order to maintain the functionality of the ecological spatial meshes, certain 'acceptable' limits must be defined. Ecological science, which can at the moment hardly establish these limits, is attempting to establish thresholds for a select set of factors that are to give warning of any undesirable irreversible situations.

Problem related to the formalization and application of concepts

Nature conservation requires important formalizations and in the establishment of many of these, the naturalists have not pooled their criteria. For instance, just as the medical sciences have an acceptably clear view of the concept of 'health' (but see Ehrenfeld 1995), ecological science meets with difficulty (Mageau *et al.,* 1995; Rapport, 1995,1998; Costanza, 1992). The term 'ecosystem health' is used, however, along with other recent terms, and emphasis is placed on the intrinsic value of natural resources, both inside and outside the economic (Rapport, 1977; Cairns and Pratt, 1995; De Graaf *et al.,* 1996; Costanza *et al.,* 1997; Daily, 1997), but perhaps people are acting more in good will than in the cold and objective manner science should pursue in order for their work to be soundly applied in this field.

The management of a territory with conservation in mind is aimed at administering the space and the natural resources it contains, while maintaining its 'health'. Thus, any policy assigning generic functions to this territory, providing for determined uses and ruling out others, should be based on the maintenance of its health. Based on this, certain uses could be profiled, promoted or prohibited. This is somewhat like the objectives pursued by a sports trainer with his pupil: to perfect his physical skills while maintaining his health. This calls for a convincing formalization in the case of ecological systems. Costanza (1992) sees the health of an ecosystem as its capacity to withstand external stress throughout time. This capacity would be reflected in the structure and function of the system. The definition, which cannot be fully precise, has interesting precedents in ideas related to ecological (Leigh, 1965; Lewontin, 1969; Margalef, 1969; May 1973; Holling, 1973; Jacobs, 1975; Orians, 1975; Rapport *et al.,* 1985; Holling, 1986). It is evident that the intensity of this external influence must be specified, by measurement, along with its severity, in accordance with the changes it would generate in the structure and function to be maintained. Cause and effect can be experimentally measured by determining suitable parameters or by making reasonable estimations (Grimm *et al.,* 1992; Montalvo *et al.,* 1993; Rapport *et al.,* 1995).

We require Information on the parameters need to define the structure of the system (biomass, diversity, etc.) and its function (energy and mineral flows, sucesional dynamics), along with the variation thresholds that would enable us to talk of the 'health' (and consequently, of 'illness') of the ecosystem. This is not easy in practice (Harte and Levy, 1975; Jacobs, 1975; Rapport, 1998) and even less to take other decisions differing much from the simple application of common sense. It is not gratuitous to highlight considerations such as love of nature (Meadows, 1996), environmental awareness of damage (Terradas, 1979), the importance of the care taken in the use of natural resources (Bernáldez 1985,1991) or the more pragmatic view of ecosystems services (Cairns and Pratt, 1995; Costanza and Folke, 1997; Costanza *et al.,* 1997).

In spite of the importance of all these considerations, hardly any attempt has been made to incorporate them, in a systematic and tabulated manner, into plans and particularly, into development projects.

Sectoring of the space

The management of protected natural areas is based on the separation of these parts of the surrounding territory by means of a boundary, on each side of which there are certain laws and rules whose application is conditioned by a policy of priority uses assigned to each part of the territory.

The idea of 'boundary' is deep-rooted in science. It helps to separate the physical and chemical properties on either side of a given surface. The impermeability of a boundary hinders an understanding of certain complex systems, and the idea of boundary has also been studied in order to account for determined types of flows and even to organize phenomena related to organization along gradients (thus the idea of 'Maxwell's devil). Ecology experts and biogeographers, who see the territory as a living tissue, have paid attention to the boundaries (ecotones, ecoclines, picnoclines), especially highlighting the interest of asymmetry and the importance of transfers through these (Van der Maarel and Westhoff, 1964; Margalef, 1975, 1981, 1991, De Pablo *et al.,* 1982; Pineda *et al.*, 1987; Casado *et al.,* 1989; Gómez Sal *et al.,* 1992).

The 'fragmentation' of the landscape has also been very much studied by conservationist biologists. This has frequently been considered a big threat to the 'integrity' of landscape function. Analysis of this threat, however, has not been developed to any great degree (see Fairman *et al.,* 1998); nor has any way of formalizing the integrity that is threatened.

Fragmentation normally refers to the generation of portions of biological communities of a given physiognomy which previously encompassed larger surfaces. Mac Arthur y Wilson's interesting ideas of insularity (1963, 1967) have hardly been incorporated at all into this idea, in spite of their great significance. Fragmentation basically introduces the idea of an impediment to boundary permeability between a given fragment and the environment and of impedance of flow. With regard to integrity, what fragmentation generates in the landscape is in reality another type of functioning which, depending on which ecological aspect or phenomenon is considered, can be considered to be desirable or not. In order to apply these ideas to the plane of conservation, we need to specify which functioning we wish to preserve, along with its significance, which is more difficult to specify than if it were biodiversity we wished to (McCoy and Mushinsky, 1994).

Conservation of connectivity

The previous considerations invite one to seriously consider the idea of the territorial tissue. This theme is very important if we take into account the socioeconomic and landscape changes that occur in some countries which have recently taken big technological steps forward. The incorporation of Spain and Portugal into the EU is being an example of this and the recent incorporation of other countries will provide new cases to be considered. Thus, in accordance with this, it seems like a good idea to take the following considerations into (Pineda *et al.,* 2002):

Although nature conservation is very much based on the demarcation of protected areas, certain ecological processes depend on horizontal dynamics which connect some parts of the space with others, these sometimes being far removed from each other (Bernáldez, 1981; Bennet, 1991, 1994; Casado *et al.,* 1985; Pineda, 1997, 2001a,b; Gómez Sal *et al.,*1992).

- The importance of those processes transcends the conservation objectives in those areas and affects the functionality of the whole territory.

- These dynamics have not yet been properly formalized and quantified, especially at regional scale.

- Big human infrastructures have clearly been conditioning socioeconomic evolution and this, in turn, directly conditions the structure of many types of landscape (Schmitz *et al.,* 2001).

- The 'ecological horizontal dynamics –human infrastructures– socioeconomic change' interference ought to be evaluated in environmental terms, integrating ecological, sociological and economic perspectives (De Juana *et al.*, 1999; Hernández and Pineda, 1998). Thus the projected enlargement of the roads network 2000-2025 throughout countries as Spain, (SEIT, 1999) is of great relevance in this context and is also an example of this interference.

Interferences between the ecological mesh and artificial infrastructures

It has been accepted that traditional agrarian activity has created a rural structure that is secularly integrated into the natural meshes (Bernáldez, 1991; Bunce *et al.,* 2001). This does not seem to be the case with the modern roads infrastructures, which appear to be detached from the natural and cultural landscapes through which they pass. It is obvious that, in the way they have been projected to date, they cause serious disruptions in ecological functioning, which also leads to uneconomic results.

In the Mediterranean Basin, whose landscape is eminently cultural, 'nodes' can be differentiated in the ecological spatial mesh, made up of localities and counties that are in a relatively good state of conservation, along with an agricultural, urban and industrial territorial 'matrix'. The nodes are forests, mountains, wetlands, steppes, etc. Different figures of protection exist for numerous areas of this type and the territory maintains an important set of zones considered 'biodiversity reservoirs' (Soulé, 1991). It is not only a case, however, of the layout of the roads circumventing these sites due to the values they contain, but the infrastructures must also avoid generating serious malfunctions in the territorial tissue.

Initially, it could be accepted that in the ecological territorial mesh, there are easily visible 'corridors' – fluvial systems, certain linear structures, the top line of mountain ranges (Bennet, 1991, 1994; Castro, 2002)–. Apart from these corridors there are other processes which are more difficult to appreciate, such as sub-surface and subterranean hydrological circulation, the transport of nutrients on slopes, the biological dynamics linked to migration and movement of species, or traditional rural functioning. All these interconnections can be relatively well conserved in some cases, but in general, little is known of their state, the real importance of their functioning or their significance.

When the nodes are protected areas, their conservation is linked in practice to their usefulness with regard to education, recreation, tourism and scientific research. This facilitates their official protection. Development activities, however, can affect those interconnections, although these activities may be clearly distant from the nodes –let us remember the famous accident in the Boliden mines in the Guadiamar-Doñana National Park area, which is just one example among many, but which is well know due to the popularity of the area (Coopers and Lybrand, 1998; Jiménez *et al.,* 1999)–. It is therefore necessary to better found the directives for the conservation of protected areas.

It is undoubtedly of great urgency to define and characterize the 'tension points' between the ecological and roads networks. To typify and then quantify the ecological connection requires the selection of ecological parameters and the measurement of their importance in natural conditions and in relation to the roads network. The theme needs to be methodically researched at regional and local scales, changing from experimental or pilot studies to the reality of land management (see, for example, Bernáldez *et al.,*1987; Montes *et al.,* 1998).

The system constituted by the present transport network and the ecological mesh could uncover 'sensitive zones', where the rupture in functionality would be more evident. This rupture can be dealt with in different ways, depending on how the functionality affects the artificial (for example, building a bridge at a crossroads) or natural (facilitating the permeability of a road) meshes. The maintenance of the natural networks is important for human economy. The projected enlargement of the Iberian roads network invites us to systematically analyze these circumstances.

There are territorial connections of unknown importance both at local and regional scale. In order to learn of their importance, we need criteria based on both concept and application. These criteria could be, among others, the following:

- of a geomorphological nature (typology of slopes and basins),
- of the edaphic type (humification, humidification capacity of the soil),
- of the hydrological type (functioning of basins, underground circulation),
- of the biogeochemical type (dynamics of nutrients on slopes),
- of a mesoclimatic nature (prevailing winds, *föhn* phenomena),
- of the biological type (different types of migrations and rhythms, influences of habitat fragmentation),
- of a rural nature (land management, livestock routes).

Characterization of the natural and artificial networks should detect the aforementioned 'sensitive zones', and will require a descriptive analysis of the present and projected infrastructures (roads, reservoirs, ports) and the likely scope of their incidence in the natural networks. Above-ground hydrological dynamics are normally considered in cases where the layout of roads intercepts the course of rivers, torrents, badlands and wadis (arroyos) –construction of waterways through embankments, etc.–, but all situations in which water flows are intercepted deserve detailed analysis. Thus the places connecting broad slopes, which act as reception basins, with more or less permeable flat wetlands, which could be deprived of the hydric laminar flow or of their hyporeic dynamics. These flat areas can be veiled wetlands, –'crypto-wetlands' (Bernáldez, 1987, 1989, 1992 a,b; Bernáldez *et al.,* 1987; Montes *et al.* 1998)–. Attention should be paid to subterranean circulation (recharge and discharge of aquifers). From the hydrological and hydrogeological points of view, the best type of road would be 'the one that doesn't touch the ground', it being raised along its theoretical layout upon piles and bridges.

The interest in incorporating environmental considerations into the planning of infrastructure layouts and works, exploitation and maintenance projects seems obvious. Infrastructures really can be incorporated into the territory, just as traditional uses were, substantially minimizing environmental costs, the layout of these being used to improve the maintenance of many valuable rural systems. It is important to prevent the enlargement of the present roads network on several countries from affecting the aforementioned factors and processes, to, at least to minimize this effect. This enlargement should consider these aspects in corridors whose theoretical layout is sufficiently wide to evaluate the problem and to establish alternatives to minimize interference –the habitual linear alternatives are really quite worthless–.

Corridors and horizontal processes

In landscape ecology the idea of scale is usually resorted to, and sets of processes encompassed within other ones of greater range are differentiated, but in reality there is no hierarchical separation between them, as physical phenomena act vertically, horizontally and synchronously (Polynov, 1956; Bernáldez, 1981). With this difficulty to be dealt with, the progressive increase of scale in territorial perception will enable us to find the detail at which the territorial components and their meshes of natural connections should condition the layout of a roads network. For instance, aspects such as distribution of unstable or expansive substrates conditions the layout of sufficiently wide corridors in order to propose, at more detailed scale, possible alternatives for the layout of roads. This observation is not only applicable to geotechnical or topographical issues, but also to environmental factors that dominate in different locations. The following can be considered:

- International connections (European, European-African, paying attention, for example, to bird migrations).
- Regional connections (for example, dynamics of rivers-estuaries, seasonal migration of livestock to mountain pastures ('transhumance').
- Connections between counties (for instance, mountains-slopes-valleys).
- Local connections (for example, seasonal migration of livestock to mountain pastures ('transterminance'), dynamics of slopes).

The functionality of connections is easily observed, for example, in certain breeds of animals that have reproductive and feeding areas in certain locations, but their dispersion and colonisation needs depend on the existence of corridors between such locations. The possibilities and probable importance of these connections are found in the surface of zones considered as nodes, the distance between equivalent nodes – depending on the specific process (for example, animal connections are different from those derived from water-flow) –and the nature of the environment or surrounding nodes and corridors –for example, a hostile environment hinders the connections(Bennet, 1991)–.

It is often thought that connections based on corridors are mainly supported upon a solid medium (the land), and can be identified as more or less continuous surfaces, with an elongated shape, like riparian forests, but also like discontinued zones which are relatively far removed from reach other, as occurs with land where infiltration and recharge of underground water occur and with the places where these waters are discharged (different types of hypogenic wetlands) –these cases do not necessarily have to respond to a continuous corridor structure, at least on the surface of the territory–.

According to these observations, it is not difficult to analyze the advantages the following types of corridors could have (Pineda *et al.,* 2002):

- Hydrographic network. Riparian systems formed by forests and other formations typical of more or less developed riparian vegetation. The vector of territorial connection is water. Not only that which flows along the river, but also that which is drained along the slopes which make up the hydrographic basin.
- Counties with an obvious introduction of traditional agrarian systems, with grids based on hedgerows, coppices and groves. The rural mesh of each county bears a relationship to the socioeconomic structure of its municipalities: this is somehow reflected in this structure and vice (Schmitz *et al.,* 2001), and the characterization of the connections should therefore incorporate parameters of this type. The spatial connections are provided by the dynamics of the land management itself (movement of livestock, materials, animals, compost, etc.)
- Peculiar slope systems, maintaining integrated wild and agrarian systems. The connection is vectorial, determined by the flow of water and materials from the export zones high on the slopes to the ones lower down. In the traditional landscape the upper parts contain more mature systems, such as forests and scrub, with a lower turnover and the persistence of organic matter in the soil. These parts can act as natural fertilizers for the lower slopes.
- Hills, mountains and water divides of the main mountain ranges. In these cases, the difficult access for humans maintains these places relatively isolated, providing an area of movement for animals that are sensitive to noise and human activity.
- Drove roads network (‘cañadas’, ‘cordeles’ ‘veredas’). These are linear structures of public ownership in those countries in which this system of

drover roads is still maintained. They probably do not act as real corridors, but rather as refuge for organisms expelled from croplands and exploited lands. The troughs and stop stations for livestock along these routes constitute unique elements of connective interest, particularly for the fauna.

- Discontinuous charging and discharging systems of underground waters, especially in the sedimentary basins of big rivers. Hypogenic wetlands. This is a physical phenomenon of connection which is of great interest in the functioning of the territorial tissue –although these structures are not easily visible in the territory (González Bernáldez *et al.,* 1989, 1993; González Bernáldez, 1988; Rey Benayas *et al.*, 1990)–. There is much work to be done in this respect with regard to incorporating these ideas into nature (González Bernáldez *et al.,* 1985; Llamas, 1988; Pfadenhauer and Grootjans, 1999; Hruby, 1999).
- Determined areas of Mediterranean 'monte' and other types of forest formations conserve certain emblematic species (bear, wolf, lynx) which require connections throughout vast areas. Relict habitats are examples of the danger of extinction of some of these species.
- Systems of active dunes, deltas and different types of marshland systems. The maintenance of these depends on phenomena which are essentially physical but which are linked to successional ecological processes of great interest for conservation.

Spatial relationships, scale and political compromise

The fragmentation of wild habitats and the degradation of these represent the continuous decline of places considered to be biodiversity reservoirs. These places are, to a certain extent, a guarantee of the permanence of 'nature' and of the possibilities of recovering and maintaining it. Interconnecting these environments is a task of global interest. Conservation policies based on the consideration of biological species or isolated parts of the territory are unsuitable in the long term. Protection of dispersal and migration patterns should be based on the recognition of their territorial connections. This constitutes the main challenge with regard to integrating development infrastructures and the territorial tissue. Local measures are insufficient in cases in which the scale of the connections encompasses large areas of territory. Protection of the Iberian lynx (*Lynx pardina*), for example, requires connecting extensive corridors of Mediterranean monte ranging from the center to the south of the Iberian

Peninsula. This species is in its own right of great emblematic value (among other reasons, no species of feline has become extinct in Europe for thousands of years), but from the ecological point of view it represents, above all, an indicator of the degree of conservation and connection between vast areas of forest. In other cases, certain habitats can maintain their own demographic self-regulating mechanisms, and the maintenance of these depends precisely on their isolation, connection thus being a disadvantage.

On commenting upon the importance of geomorphological and hydric factors, we referred to certain processes whose maintenance depends on the protection of the biogeochemical dynamics. These dynamics operate throughout different habitats. The hydrographic network represents a synthesis of the connection between successive vectorial processes. Phenomena of export, transit and accumulation of water, nutrients and organic matter represent the routes of connection along the slopes. The characteristics of estuaries and the formation of deltas and coastal marshland areas constitute a geographic synthesis of these dynamics. Along the regional gradients of the basins, these processes are repeated at different scales of detail. The rural grids, based on maintaining hedges and thickets at the heart of the territory subjected to cultivation or grazing, slow these processes down, without impeding the gravitational connection that generates them. Along the rivers, the gallery forests, wherever they are maintained, contribute to this mesh and can also act as corridors (Sterling, 1996).

Some nodes of the network of natural infrastructures are spaces with fundamentally mature ecosystems –with a low turnover (with a tendency to accumulate biomass, wood, firewood and humus in the soil) and essentially wild–,but in other cases, the importance of the nodes may lie in their functionality as ‘sources’ in the movement of natural components, connected with other generally productive spaces (such as the low and mid-slope agricultural lands and pastures) which act as ‘sinks’. The vectorial connections between mountains and piedmonts, or between hills and valleys, are examples of this. The fertility of the latter is determined by the functionality of the mountain-pediment or slope-thalweg systems (flows of water and nutrients, movements of fauna and livestock, etc.). Throughout practically the whole Mediterranean, the monte-pasture and monte-crops relationship is based on the maintenance of the former on rises, hills or upper slopes, and the latter on the mid and lower slopes. The use of chemical fertilizers, which is widespread, exaggerated and linked to a fictitious agrarian economy, is insufficient in the long term in order to maintain these systems, and the rupture of these connections should therefore not be underestimated.

Another case of the type of source-sink connection is constituted by coastal dunes, whose contributions of sand come from the sea and the beaches, the sink being represented by the dunes themselves. There are many cases of rupture of this connection by the layout of roads.

These latter cases correspond to 'open' segments of the network, which dissipate energy. In other cases, the connections through the corridors affect mature systems, and appear to be controlled by both biological migratory phenomena and by physical processes. Both types of connections can maintain throughout the year 'peak' activities and 'rest' activities, depending on seasonal climatic conditions, fauna migration, etc.

The hills, mountain tops and top lines of mountain ranges also constitute corridors for biological migrations and 'source' nodes for `processes of the type already mentioned. Conservation of these is rarely affected by the layout of roads, but their functionality as sources is.

Finally, in some countries the drover roads networks still maintain their essential structure. The existence of these facilitates the maintenance of the rural mesh. Roads networks have often altered, destroyed or used them, the engineers failing to seek alternatives. The conservation and rehabilitation of the sections destroyed appears to be imperative and should be in itself and objective of the future roads network. Overlapping the planned network of infrastructures with the natural ecological network may very well lead to the total decomposition of the latter, or, to the contrary, to its maintenance, provided that the functionality of the different types of nodes, sinks and flows maintain their efficiency.

References

Bennett, G. (Ed.), 1991. *Eeconet, An European Ecological Network*. Inst. European Environm. Policy Publ., Arnhem.

Bennett, G. (Ed.), 1994. *Conserving Europe's Natural Heritage. Towards a European Ecological Network*. Graham and Trotman/M.Nijhoff, Internat. Environm. Law & Policy Series, Dordrecht.

Bernáldez, F.G., 1981. *Ecología y Paisaje*. Blume, Madrid.

Bernáldez, F.G., 1985. *Invitación a la ecología humana. La adaptación efectiva al entorno*. Tecnos, Madrid.

Bernáldez, F.G., 1987. Las zonas encharcables españolas: el marco conceptual. In: *Bases científicas para la protección de los humedales en España*. Real Acad. Ciencias Exactas, Físicas y Naturales, Madrid: 9-30.

Bernáldez, F.G., 1989. Ecosistemas áridos y endorreicos españoles. In: *Zonas Áridas en España*. Real Acad. Española Ci. Exactas, Físicas y Naturales. Madrid: 66.109.

Bernáldez, F.G., 1991. Diversidad biológica, gestión de ecosistemas y nuevas políticas agrarias. In: F.D. Pineda *et al.* (Eds.), *Diversidad Biológica*. SCOPE. WWF-Adena, F. Areces. Madrid: 23-32.

Bernáldez, F.G., 1992a. Ecological aspects of wetland/groundwater relationships in Spain. *Limnetica* 8:11-26.

Bernáldez, F.G., 1992b. *Los paisajes del agua: terminología popular de los humedales*. J.M. Reyero, Eds. Madrid.

Bernáldez, F.G.; Herrera, P.; Levassor, C.; Peco, B. and Sastre, A., 1987. Las aguas subterráneas en el paisaje. *Investigación y Ciencia* 127:8-17.

Bernáldez, F.G.; Rey Benayas, J.M.; Levassor, C. and Peco, B., 1989. Landscape ecology of uncultivated lowlands in central Spain. *Landscape Ecology* 3(1): 3-18.

Bunce, R.G.H.; Pérez-Soba, M.; Elbersen, B.S.; Prados, M.J.; Andersen, E.; Bell, M. and Smeets, P.J.A.M. (Eds.), 2001. *Examples of European agri-environment schemes and livestock systems and their influence on Spanish cultural landscapes*. Alterra, Wageningen.

Burel, F. and Baudry, J., 2001. *Ecologie du paysage: concepts méthodes et applications*. Tec Doc-Lavoisier, París.

Cairns, J. Jr. and Pratt, J.R., 1995. The relationships between ecosystem health and delivery of ecosystem services. In: D.J. Rapport; C. Gaudet and P. Calow (Eds.), *Evaluating and monitoring the health of large-scale ecosystems.* Springer-Verlag, Heidelberg: 273-294.

Casado, M.A.; de Miguel, J.M.; Sterling, A.; Peco, B.; Galiano, E.F. and Pineda, F.D., 1985. Production and spatial structure of Mediterranean pastures in different stages of ecological succession. *Vegetatio* 64: 75-86.

Casado, M.A.; Abbate, G.; Blasi, C. and Pineda, F.D., 1989. Spatial heterogeneity in a clearing in aturkey oak (*Quercus cerris*) wood: pattern diversity analysis. *Vegetatio* 79: 143-149.

Castro, H. (Dir.), 2002. *Integración territorial de espacios naturales protegidos y conectividad ecológica en paisajes mediterráneos.* Junta de Andalucía, Sevilla.

Coopers and Lybrand., 1998. *Informes sobre el seguimiento del Accidente de Aznalcóllar.* Junta de Andalucía, Sevilla.

Costanza, R. and Folke, C., 1997. Valuing Ecosystem Services with Efficiency, Fairness and Sustainability as Goals. In: G.C. Daily (Ed.), *Nature's services: societal dependence on natural ecosystems.* Island Press, Washington.

Costanza, R., 1992. Toward an operational definition of health. In: R. Costanza; B. Norton and B. Haskell (Eds.), *Ecosystem Health: New Goals for Environmental Management.* Island Press, Washington: 239-255.

Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; O'Neill, R.V.; Paruelo, J.; Raskin, R.G.; Sutton, P. and Belt, M. Van den., 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

Daily, G.C., 1997. *Nature's services: societal dependence on natural ecosystems.* Island Press, Washington.

De Graaf, H.J.; Musters, C.J.M. and ter Keurs, W.J., 1996. Sustainable development: looking for new strategies. *Ecological Economics* 16: 205-216.

De Juana, E.; Díaz-Pineda, F.; Hedo, D.; Hernández, S.; Ladero, M.; Nardiz, C. and Valero, M.A., 1999. Marco Director de Carreteras: Metodología para el establecimiento de los Criterios Ambientales a incluir en los Estudios de Carreteras. Cartografía básica Medioambiental. *Informe para la Secretaría de Estado de Infraestructuras y Transportes*, Ministerio de Fomento, Madrid, 177 pp.

De Pablo, C.L.; Peco, B.; Galiano, E.F.; Nicolás, J.P. and Pineda, F.D., 1982. Space-time variability in Mediterranean pastures analysed with diversity parameters. *Vegetatio* 50: 113-125.

Ehrenfeld, D., 1995. The marriage of ecology and medicine: are they compatible? *Ecosystem Health* 1: 15-22.

Fairman, R.; Mead, C.D. and Williams, W.P., 1998. Environmental Risk Assessment: Approaches, Experiences and Information Sources. European Environmental Agency. *Environm. Issues Series* 4. Copenhagen.

Fortescue, J.A.C., 1980. *Environmental Geochemistry.* Springer Verlag, Berlin.

Glazovskaya, M.A., 1963. On geochemical principles of the classification of natural landscapes. *Internat.Geol. Rev.* 5(11): 1403-1431.

Gómez Sal, A.; Rodríguez, M.A. and de Miguel, J. M., 1992. Matter transfer and land use by cattle in a dehesa ecosystem of Central Spain. *Vegetatio* 99-100: 345-354.

González Bernáldez, F., 1988. Water and landscape in Madrid. Possibilities and limitations. *Landscape and Urban Planning* 16: 69-79.

González Bernáldez, F.; Pérez, C. and Sterling, A., 1985. Areas of evaporative discharge from aquifers: Little known Spanish ecosystems deserving protection. *J. Env. Management* 21: 321-330.

González Bernáldez, F.; Rey Benayas, J.M. and Martínez, A., 1993. Ecological impact of groundwater extraction on wetlands. *J. of Hydrology* 141: 219-238.

Grimm, V.; Schmidt, E. and Wissel, C., 1992. On the application of stability concepts in ecology. *Ecol. Mod.* 63: 143-161.

Harte, J. and Levy, D., 1975. Sobre la vulnerabilidad de los sistemas perturbados por el hombre. In: W.H. van Dobben and R.H. Lowe-McConnell (Eds.), *Conceptos unificadores en ecología*. Blume, Barcelona: 263-284.

Hernández, S. and Pineda, F.D., 1998. *Ferrocarril de alta velocidad Madrid-Barcelona-Frontera Francesa. Directrices para la restauración ambiental del trazado*. Gestor de Infraestructuras Ferroviarias, GIF. Mº Fomento, Madrid, 45 pp.

Holling, C.S., 1973. Resilience and Stability of ecological systems. *Ann. Rev.Ecol.Syst.* 4: 1-23.

Holling, C.S., 1986. The resilience of terrestrial ecosystems: local surprise and global change. In: W.C. Clark and R.E. Munn (Eds.), *Sustainable development of biosphere*. Cambridge Univ. Press, New York: 292-317.

Hruby, T., 1999. Assessments of wetland functions: What they are and what they are not. *Env. Manag.* 23(1): 75-85.

Jabobs, J., 1975. Diversidad, estabilidad y madurez en ecosistemas influidos por las actividades humanas. In: W.H. van Dobben and R.H. Lowe-McConnell (Eds.), *Conceptos unificadores en ecología*. Blume, Barcelona:236-262.

Jiménez, J.J.; Salvo Tierra, E. and Serrano, J. (Dirs.)., 1999. La Estrategia del Corredor Verde del Guadiamar. *Conclusiones del Seminario Internacional sobre Corredores Ecológicos*. Junta de Andalucía, Sevilla.

Leigh, E.G., 1965. On the relationship between productivity, biomass, diversity and stability of a community. *Proc. Nat. Acad. Sci.* 53:777-783.

Lewontin, R.C., 1969. The meaning of stability. In: Diversity and stability in ecological systems. Brookhaven Nat. Lab. Springfield, *V. Symp. Biol.* 22:13-24.

Llamas, M.R., 1988. Conflicts Between Wetland Conservation and Groundwater Exploitation. *Environ. Geol. Water Sci.* 11(3): 241-251.

Maarel, E. Van der and Westhoff, V., 1964. The vegetation of the dunes near Oostvoorne. *Wentia* 12:1-61.

Mac Arthur, R.H. and Wilson, E.O., 1963. An equilibrium theory of insular zoogeography. *Evolution* 17: 373-387.

Mac Arthur, R.H. and Wilson, E.O., 1967. *The theory of island biogeography*. Princeton Univ. Press, Princeton.

Mageau, M.T.; Costanza, R. and Ulanowicz, R.E., 1995. The development and initial testing of a quantitative assessment of ecosystem health. *Ecosystem Health* 1: 201-213.

Margalef, R., 1969. Diversity and Stability: A practical proposal and model of interdependence. Brookhaven Nat.Lab. Springfield, *V. Symp. Biol.* 22:25-37.

Margalef, R., 1981. *Limnología*. Omega, Barcelona.

Margalef, R., 1991. *Teoría de los sistemas ecológicos*. Publs. Univ. de Barcelona, Barcelona.

May, R.M., 1973. *Stability and Complexity in Model Ecosystems*. Princeton Univ. Press, Princeton.

McCoy, E.D. and Mushinsky, H.R., 1994. Effects of fragmentation on the richness of vertebrates in the Florida scrub habitat. *Ecology* 75 (2): 446-457.

Meadows, D., 1996. Más allá de los límites. In: F.D. Pineda (Ed.), *Ecología y desarrollo*. Editorial Complutense, Madrid: 57-69.

Montalvo, J.; Ramírez, L.; De Pablo, C.T.L. and Pineda, F.D., 1993. Impact Minimization through Environmentally-based Site Selection: a multivariate approach. *J. of Environm. Management* 38:13-25.

Montes, C.; Borja, F.; Bravo, M.A. and Moreira, J.M., 1998. *Reconocimiento biofísico de Espacios Naturales Protegidos. Doñana: una aproximación ecosistémica*. Consejería de Medio Ambiente, Sevilla.

Orians, G.H., 1975. Diversidad, estabilidad y madurez en los ecosistemas naturales. In: W.H. van Dobben and R.H. Lowe-McConnell (Eds.), *Conceptos unificadores en ecología*. Blume, Barcelona: 174-189.

Pfadenhauer, J. and Grootjans, A., 1999. Wetland restoration in Central Europe: aims and methods. *Appl. Veget. Sci.* 2: 95-106.

Pineda, F.D., 1991. Conclusions of the international symposium on biological diversity of Madrid, J. *Veget. Science* 1: 711-712.

Pineda, F.D., 1997. Las tramas territoriales ante la idea de desarrollo. *Naturzale* (Soc. de Estudios Vascos) 12:49-55.

Pineda, F.D., 2001a. Las deficiencias ambientales de un Plan Hidrológico Nacional. In: P. Arrojo (Ed.), *El Plan Hidrológico Nacional a Debate*. Bakeaz, Bilbao.

Pineda, F.D., 2001b. Espacio y tramas de funcionamiento en el paisaje mediterráneo. In: M. Morey and J. Mayol (Eds.), *El paisaje y el hombre: valoración y conservación del paisaje natural, rural y urbano*. Parques Nacionales. Ministerio de Medio Ambiente, Madrid: 37-54.

Pineda, F.D.; Casado, M.A.; Peco, B.; Olmeda, C. and Levassor, C., 1987. Temporal changes in therophytic communities across the boundary of disturbeb-intact ecosystem. *Vegetatio* 71: 333-339.

Pineda, F.D.; Montalvo, J.; Casado, M.A. and De Miguel, J.M. (Eds.), 1991. *Diversidad Biológica-Biological Diversity*. SCOPE. WWF-Adena, F. Areces, Madrid.

Pineda, F.D.; Schmitz, M.F. and Hernández, S., 2002. Interacciones entre infraestructuras y conectividad natural del paisaje. In: *I Congr. Ingeniería Civil, Territorio y Medio Ambiente*. Col. Ing. C.C. y Puertos, Madrid. Vol. I: 191-214.

Polynov, B.B., 1956. *Izbr trudy*. Izd.-vo AN. SSSR, Moscov.

Rapport, D.J. and Regier, H.A., 1995. Disturbance and stress effects on ecological systems. In: B.C. Patten and S.E. Jorgenson (Eds.), *Complex ecology: the part-whole in ecosystems*. Prentice-Hall, Englewood Cliffs.

Rapport, D.J. and Turner, J.E., 1977. Economic models in ecology. *Science* 195: 367-373.

Rapport, D.J., 1995. Ecosystem health: more than a metaphor? *Environ.Vaues* 4: 287-309.

Rapport, D.J., 1998. Defining Ecosystem Health. In: D. Rapport; R. Costanza; P.R. Epstein; C. Gaudet and R. Levins (Eds.), *Ecosystem Health*. Blacwell, London: 18-33.

Rapport, D.J.; Regier, H.A. and Hutchinson, T.C., 1985. Ecosystem behaviour under stress. *Am. Naturalist* 125: 617-640.

Rey Benayas, J.M.; Bernáldez, F.G.; Levassor, C. and Peco, B., 1990. Vegetation of groundwater discharge sites in the Douro basin, central Spain. *J. of Veget. Sci.* 1: 461-466.

Schmitz, M.F.; De Aranzabal, I.; Rescia, A. and Pineda, F.D., 2001. Implications of socio-economic changes in Mediterranean cultural landscapes. *Inst. Geographici Tartuensis* 92 (2):788-793.

SEIT, 1999. *Marco Director de Carreteras. Cartografía Básica Medioambiental*. Secretaría de Estado de Infraestructuras y Transportes. Ministerio de Fomento, Madrid.

Solntsiev, V.N., 1974. O niekotorikn fundamentalnykh svoistakh gheosistemnoi struktury. In: *Methody kompleksnykh issledovanii gheosistem*. Akademya Nauk SSSR, Irkutsk.

Soulé, M.E., 1991. Conservation: tactics for a constant crisis. *Science* 253: 744-750.

Sterling, A., 1996. *Los sotos, refugios de vida Silvestre*. Publ. Mº Agricultura, Madrid.

Terradas, J., 1979. *Ecología y educación ambiental*. Omega, Barcelona.