

Ecological networks to balance development and conservation: examples from land-use planning in the Netherlands, USA and Argentina

Hubert N. van Lier and Gerrit J. Carsjens

Land Use Planning Group, Wageningen University
P.O. Box 47, 6700 AA Wageningen, The Netherlands

Abstract

Current land-use planning is caught between the increasing pressure on the rural area for economical development and the need to preserve natural landscapes and reserves. The challenge is to find a balance between both objectives in land use plans. Ideally ecosystems, habitats and species can be protected by preserving large areas from human exploitation. However, this often conflicts with the demand for economical development, especially in the more urbanized areas. The concept of ecological networks offers a way of balancing these two conflicting demands by integrating biodiversity conservation with the exploitation of natural resources. This is done by embedding areas in the landscape, such as corridors and stepping stones, which are necessary to ensure the continued functioning of ecological processes or the viability of species populations. To implement the concept, land-use planning plays an important role. This paper presents a brief description on the fundamentals of the concept of ecological networks and discusses the application of the concept in land-use planning. Three examples of the application of the concept will be given. The first example deals with a study to apply the concept in a human dominated, agricultural landscape in the Netherlands. The second one focuses at the application of the concept in urban landscapes in the USA. The third example includes a first application of the concept in Argentina, combining land-use changes and habitat protection. The results will be discussed and conclusions drawn on the applicability of the concept in land-use planning.

Keywords: Ecological network, multiple land-use planning, spatial concept, sustainability

1 Introduction

'Land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adapt the best land-use options' (FAO 1993). This definition embraces the systematic approach of possibilities for different land uses in the future, and also the (felt) need for changes and willingness to execute the plan. Land-use plans today are caught up between two seemingly contradictory dimensions: environmental conservation and economic development. Conservation refers to the safeguarding of our natural systems and resources, while developments refer to durable socio-economic existence. But they are, as often expressed, not independent: 'We cannot save the environment without development and that we cannot continue to develop anywhere unless we save the environment' (Science Council of Canada 1989) or: 'The economy and its participants exist within the environment, not outside it: we cannot expect to maintain economic prosperity unless we protect the environment and our resource base, the building blocks of development' (National Task Force on Environment and Ecology 1987) and: 'Just as long-term economic growth depends on a healthy environment, so the maintenance of a healthy environment requires continued economic development' (Aitken 1988). Both

dimensions are, in some way or another, related to sustainability. The term sustainability can be viewed at or be defined from several angles. In most cases its notion is based upon the protection of our natural resources because of its production and reproduction qualities for now and forever, if properly managed or used. There are however more dimensions in the term. Bryden (1994) distinguishes at least three different meanings:

- Sustainability in the meaning of husbandry. In this sense it is related to such terms as continuity, durability and exploitation of natural resources over long periods of time. It is also referring to certain methods by which mankind manages its lands, e.g. crop rotation systems, and allowing land to lie fallow. These methods are meant to create possibilities for the soil and water systems to restore in terms of good and sufficient water, healthy soil structures etc. This refers strongly to the physical and economic sustainability on the long run.
- Sustainability in terms of interdependence. This meaning is strongly related to the spatial dimension of sustainability. It refers to such aspects of fragmentation (which has contradictory meanings for farming, nature and outdoor recreation and is therefore an important land-use planning aspect), and relations between different land uses (e.g. cropped areas and semi-natural vegetation). It is this meaning of sustainability that gets a great deal of attention in land-use planning studies (e.g. Linehan and Gross 1998; Steiner 2000; Opdam et al 2006), since there still is a great lack of knowledge, there are many uncertainties, while there is often a lack of clear policies in this regard.
- Sustainability in terms of ethical obligations to future generations. This refers to the many observed losses and depletions of the natural resources in combination with the expected increase in population. Particularly known ones are fossil fuels, forests, soil-losses, water and air pollution, loss of nature areas and old landscapes etc. It is clear that, both in the field of better management and of restorations, much needs to be done for future mankind.

It is obvious that land-use planning aims primarily to the second meaning. In this paper, we will explore the opportunities for land-use planning to deal with the dilemma between economical development and environmental conservation, with special emphasis on the use of the concept of ecological networks in land-use planning. Section 2 provides a brief review of the use of spatial concepts in land-use planning, with special emphasis on the application of the concept of ecological networks. The application will be demonstrated in Section 3 for three different types of human-dominated landscapes in The Netherlands, the USA and Argentina. Some conclusions on the use of this and other concepts in land-use planning will be drawn in Section 4.

2 Spatial concepts

There is a growing tendency among land-use planners to work with spatial concepts that address the problems of conservation and development as well as to meet the challenge of sustainability. In this sense these concepts can be seen as a planners answer to the given dilemmas. Examples of spatial concepts are the integration versus segregation concept, the framework concept and the ecological network concept.

The integration versus segregation concept (see e.g. Oostindie et al. 2006) tries to restore the many relationships between the several land uses in the countryside. Integration seeks to correct upon the segregation, which was a dominant change during the last centuries. The integration concept puts restrictions on the developments of each land-use type because of a desired or chosen development of another. The concept is

actually at the basis of landscape ecology: land-use types (such as farming, outdoor recreation; infrastructure; housing etc.) have to be planned and developed in such a way that the basic ecology of the landscape is kept to function.

The framework-concept is fundamentally based upon a distinction into a low dynamic part of the rural system (nature, ecosystem) and a highly dynamic one (farming, housing, recreation and transport). Extensive research on the changes in Dutch rural systems (Kerkstra and Vrijlandt 1990; van Buuren 1991; van Buuren and Kerkstra 1993) showed e.g. that:

- The natural variation in moisture content (wet/dry) and in nutrition levels (eutrophic/oligotrophic) of soils diminished.
- The disappearance of variation in external production conditions resulted in a sharp decrease in number and species of natural vegetation and wildlife.
- The visual character of the landscape became more uniform: contrasts between largely open areas and small-enclosed areas (with small-scale farmlands) disappeared.

The framework concept seeks a correction by a spatial segregation of intensively used lands, requiring a flexible layout and use, and extensive (used) lands, requiring stability. This involves the planning of a durable and stable framework: an interconnected pattern of zones in which nature management, forestry, outdoor recreation and water management are concentrated. Such a framework envelops large open areas in which optimal farming is possible.

The ecological network concept is founded on the island theory of MacArthur and Wilson (1967) and the application of this theory to mainland situations and upon the metapopulation theory (Levins 1970; Hanski and Gilpin 1997). The fragmentation of nature reserve areas in rural landscapes created 'nature islands'. The increasing isolation of these islands determined whether certain populations of plants and animals can survive over time. The concept of an ecological network is a response to this fragmentation and isolation. An ecological network is a constellation of landscape elements, linking ecosystems, that is functional for the dispersion of species in a landscape (see also Opdam et al. 2006). Several studies have demonstrated the specific properties on which ecological networks are developed or are adapted as criteria for the development of the concept (see examples in Cook and van Lier 1994). Connectivity, indicator species, stepping stones, core regions, metapopulations, all are important elements considered in the ecological network approach. Such a network consists of core regions, nature development regions and connecting areas. The core regions are areas of existing ecological values that are of international or national significance. The nature development areas are areas that offer perspectives for the development of nature values of (inter)national significance or for a significant increase in present nature values. The objective of the connecting zones is to improve and develop the possibilities for migration within and between the core regions for (some) species. It is assumed that providing for the needs of these species can be of positive significance for other species in the core areas. The main connection between nature areas can be formed through corridors of sufficient length and width, good variations in soils, heights, cover, waters etc. In practice this can be achieved by combining it with existing watercourses, wet areas, small hedgerows or other landscape elements and in specific cases also with main drainage systems, rural roads etc. The smaller sideway connections in their turn can follow field borders, small water courses, unpaved rural roads etc. to create a connection with smaller nature preserves. In intensively farmed regions the concept is a challenge to develop it in such a way that it achieves its own goals as well as it still makes profitable farming possible. If the land is used for other functions, such as forestry and/or outdoor recreation the challenge is there as well. The combination of enjoying the

rural countryside as well as of growing and harvesting wood combined with the concept of ecological networks is another challenge to be achieved.

Attempts to delineate ecological networks in agricultural landscapes are often restricted to listing and classification of reserves that are already protected or that have to be protected (see e.g. Margules et al. 1988; Bischoff and Jongman 1993; Csuti et al. 1997). The idea of ecological or ecosystem networks is that it may benefit biodiversity by facilitating exchange of individuals through stepping stones or corridors between the reserves (Forman 1995). The concept of ecological networks received a lot of attention in land-use planning (Smith and Helmund 1993; Cook and van Lier 1994; Arts et al. 1995; Ahern 2002; Opdam et al. 2006). However, the application of the concept raises many questions. Some important questions are related to knowledge on the design and functioning of networks for the desired species (e.g. Vos et al. 2001). Another important question is how to design an ecological network in balance with other land uses in human dominated landscapes (see e.g. Leitão and Ahern 2002). Much research has been done in this respect. The next section will describe three different cases: an agricultural landscape in The Netherlands (3.1), an urban landscape in the USA (3.2) and a rapidly transforming natural landscape in Argentina (3.3).

3 The cases

3.1 The Netherlands: Ecological networks in agricultural landscapes

When the habitat of a species is fragmented and the distances between patches of habitat are large relative to the movement distances of the species, it can be expected that the degree of habitat connectivity affects processes in populations. However, to what extent does the degree of habitat connectivity determine these processes? And if the degree of habitat connectivity has a large impact on the regional persistence of a species, at what spatial scale effects can be expected? To address these questions, the effects of the degree of connectivity on colonization in fragmented habitat in different agricultural areas in the Netherlands were studied (van Langevelde 1999). The main research questions were:

- What are the variables that can measure the degree of connectivity of habitat patches, as well as are differences in this degree of connectivity related to the probability that patches are colonized?
- Is habitat selection in landscapes with fragmented habitat limited compared to landscapes with contiguous habitat?
- How can ecological networks be optimally allocated in agricultural landscapes, while taking into account the different land-use suitabilities?

When the degree of connectivity of a patch is low, it may have a low colonization probability. Therefore, the habitat patches and the distances between these patches as networks were modeled (see Figure 1). It was assumed that a linkage between patches exists in terms of potentials for exchange of individuals, when the distances between patches are less than a certain threshold distance. In landscapes with fragmented habitat for a certain species, such network appears as so-called non-connected networks consisting of disjointed subsets of patches. Van Langevelde et al. (1998) derived parameters that measure the degree of connectivity of the patches in those networks. To vary the spatial scale, at which effects of fragmentation may be noticeable, the distances across which exchange of individuals can take place (i.e., the maximum

dispersal distance) were varied. With small threshold distances between habitat patches few patches are connected, whereas with large distance more patches are connected.

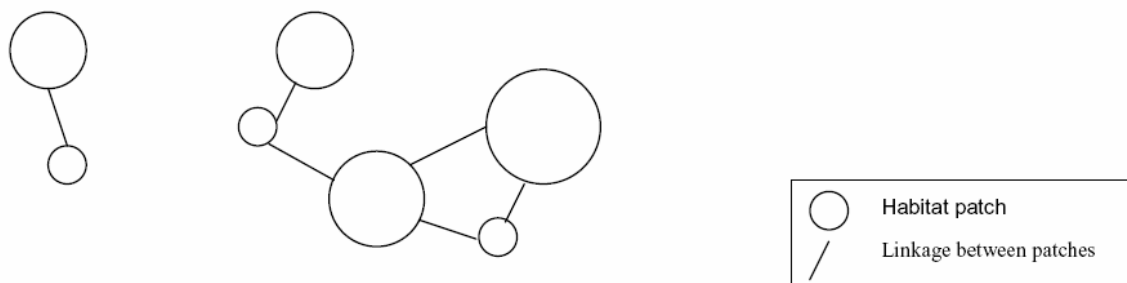


Figure 1. Network of habitat patches.

For three regions with fragmented deciduous forest in the Netherlands, the degree of connectivity of each forest patch was calculated based on the parameters as described by van Langevelde et al. (1998). The sum of these connectivity values provides a measure for the overall connectivity of the region. For each threshold distance, the overall degree of connectivity is presented in Figure 2. In the three regions, the amount and spatial configuration of the habitat is assumed to be constant, whereas the dispersal distance of species is varied. The value of the overall degree of connectivity depends upon the number of patches and the distances between them. If the mean dispersal distance of a forest species is more than about 3.5 km, the overall degree of connectivity is relatively constant. When a species of deciduous forest has a mean dispersal distance above this threshold of 3.5 km, the forests in the area Midden Brabant can be considered to be sufficiently connected directly or indirectly with each other. Below this threshold, the overall degree of connectivity decreases rapidly. Species with mean dispersal distances below this threshold may experience effects of constrained dispersal. In the area Zuidwest Drenthe, this critical threshold is approximately 4 km and in Noordoost Twente approximately 2.5 km. The latter region is less fragmented from the point of view of habitat connectivity. In these regions, we can expect that for species of deciduous forests, with mean dispersal distances less than these thresholds, effects of fragmentation can be expected. One of the species of deciduous forests, the European nuthatch *Sitta Europaea*, was used to test the relationship between the degree of connectivity of the forest patches and the colonization probability of each patch. The nuthatch is a songbird of deciduous forests that defends its territory the year round. Previous research indicated that nuthatches are sensitive to fragmentation of their habitat (van Dorp and Opdam 1987; Verboom et al. 1991; Matthijsen and Currie 1996). In fragmented habitat, the mean dispersal distance may be about 3 km (Matthijsen et al. 1995). So in the regions mentioned above, effects of habitat fragmentation can be expected.

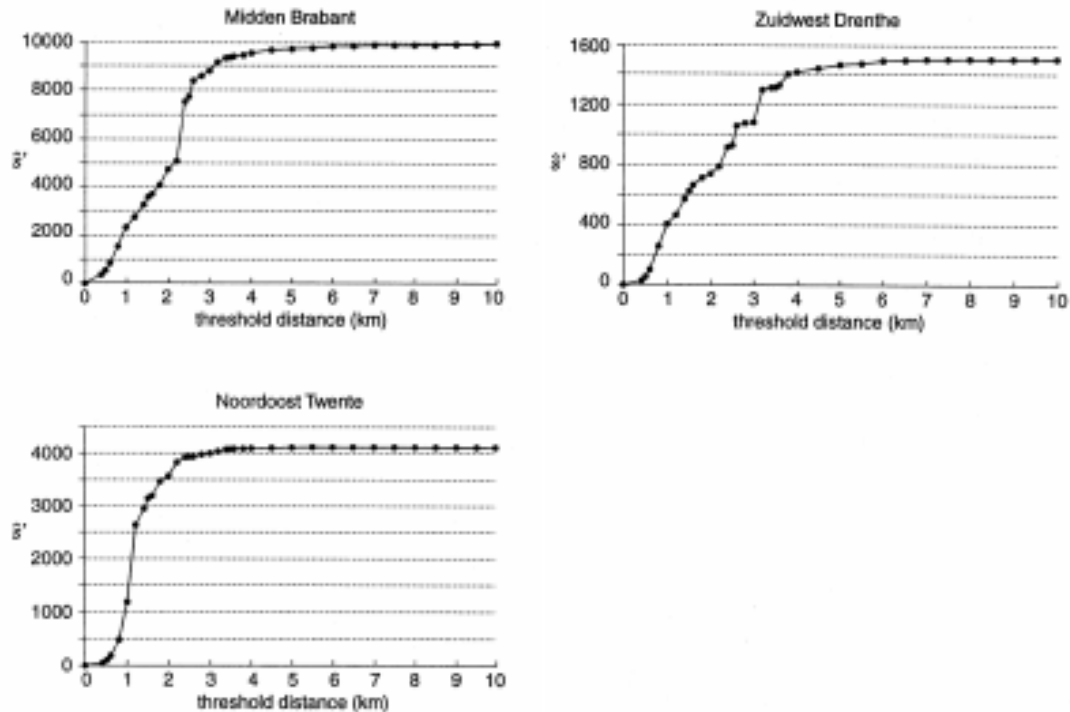


Figure 2. The overall degree of connectivity of three regions with fragmented deciduous forests in the Netherlands calculated for different threshold distances.

Van Langevelde (1999) found that the colonization probability of remote patches is lower than patches located close together. For nuthatches, distances between forests play a dominant role in the degree of connectivity. When the low degree of connectivity constrains the colonization of patches, patches with suitable habitat can remain unoccupied (e.g., after a local extinction due to a severe winter). Also other effects of the fragmentation of nuthatch habitat are studied: on mating success (Matthijsen and Currie 1996) and breeding success (van Langevelde 1999). The question was how to apply this knowledge in land-use planning, in which the effects of isolation are to be mitigated. Therefore, the model MENTOR was developed (van Langevelde et al. 2000), based upon the findings for the degree of connectivity for nuthatches (as a model species). MENTOR or Model for Ecological Networks as Tool for Optimization of land-use Reallocation, has been applied for the 'De Leijen' region in the Netherlands. The objective of MENTOR is to assign locations for stepping stones between existing nature reserve sites. The assignment of the stepping stones is based on ecological guidelines derived from knowledge about population dynamics of the model species. Based on literature and field studies, two generally accepted principles for reserve design could be applied for the habitat of the nuthatch:

- Large habitat patches that support large populations of the species support this species for longer periods than small patches that support fewer individuals.
- Habitat patches that are sufficiently connected to allow dispersal support populations for longer periods than habitat patches that are less connected.

The following guidelines for the habitat network of the nuthatch were used (Table 1).

Table 1. Threshold distances for an acceptable probability on successful dispersal of nuthatches between the distinguished size classes of habitat patches.

From:	To:	
	1–3 ha	> 3 ha
1–3 ha	1 km	3 km
> 3 ha	3 km	3 km

Enlargement of existing reserves and addition of new sites to enhance the connectivity between reserves implies a change of use and vegetation cover of areas that are currently in use by other land use. Thus, there will be competition between these other land uses and the need for preserving biodiversity. This competition becomes stronger when the suitability of the land for the competing uses is high and can often be understood in basic economic terms of supply and demand (van Lier 1994). The model MENTOR accommodates the suitability of the land for habitat and for other land uses. The results of MENTOR could be evaluated with a model that simulates the dynamics of populations in a set of habitat patches (Verboom 1996). Figure 3 shows the simulated average occupation degree of patches in the present and the planned situation. The average proportion of occupied habitat is 23% in the present situation. Due to the planning of new habitat, the average proportion of occupied habitat increases to almost 40% (Table 2). There is a clear relationship between the average proportion of occupied habitat and the survival of nuthatch populations.

Table 2. Summary of the results of the allocation of an ecological network in 'De Leijen'.

	Present	Planned
<i>Effects on landscape pattern</i>		
Amount of deciduous forests (ha)	741	1029
Number of habitat patches	100	121
<i>Effects on nuthatch populations</i>		
Proportion of occupied habitat (%)	23	38

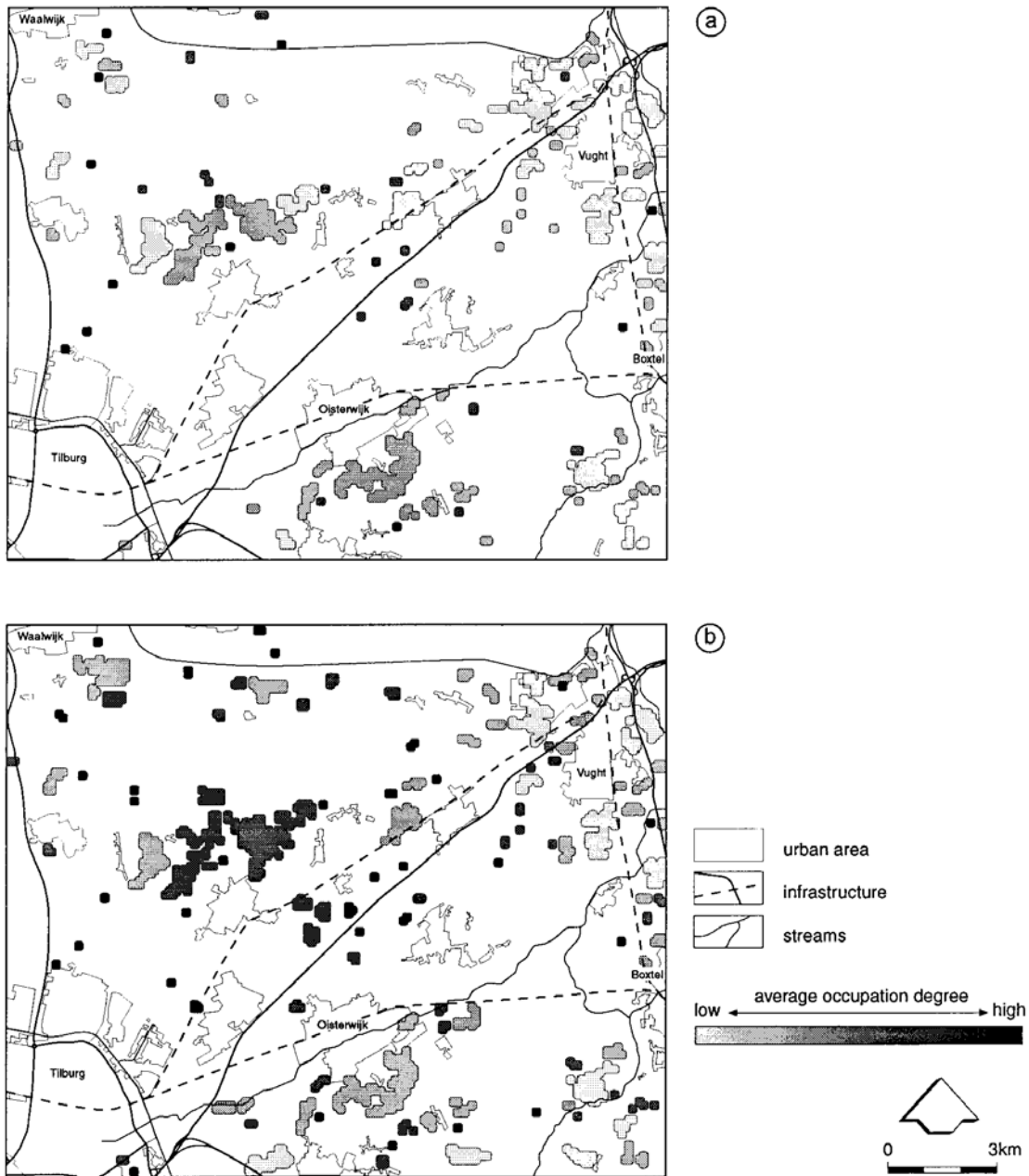


Figure 3. Average occupation degree of patches for the present situation (a) and the planned situation (b).

3.2 USA: Ecological networks in urbanized areas

Although the concept of ecological networks is primarily created for rural, open areas where socio-economic and technological developments are endangering the ecosystems, it is also increasingly studied for application in urbanized areas. In a fundamental research Cook (2000) addressed the question whether the planning of an ecological network in an urban landscape is viable. To this end this main question was split into two principal research objectives:

- Can a planning method integrate ecological concepts, and in particular the concept of ecological networks, into the urban planning process?
- Can the establishment of an ecological network improve the viability of ecological systems in an urban context?

The research, applied in Phoenix, Arizona in the USA, used a planning method, characterized as an hierarchical systems approach. Analysis and planning occur at three scales: (1) regional scale (the landscape), (2) municipal scale (the community) and (3) local scale (the site). The method included 10 steps, such as the analysis of political and natural boundaries, historical data, natural and cultural resources, and hydrologic habitat. Furthermore it included the establishment of priorities for ranking and integrated uses, the identification of sites for restoration, preservation and management as well as plans for hydrologic habitat and cultural opportunities. After the plans were made, three principal analyses were realized, a patch content analysis, a corridor content analysis and a network structure analysis. The results of the application and analysis of an ecological network in the Phoenix-area are presented in Table 3.

Table 3. Results of the application of the concept of ecological networks in an urbanized area (Cook 2000).

Analysis	Results
a) patch content analysis	1.1 10% increase in mean native vegetation coverage 1.2 14% increase in matrix utility value 1.3 15% increase in naturalness
b) corridor content analysis	2.1 19% increase in mean corridor filter width 2.2 9% increase in mean vegetation coverage 2.3 15% increase in matrix utility values 2.4 59 gaps or barriers in existing corridor eliminated 2.5 17% increase in naturalness
b) network structure analysis	3.1 3% increase in overall matrix utility index 3.2 20% increase in the degree of network circuitry 3.3 12% increase in the gamma index of connectivity

3.3 Argentina: Ecological networks in areas with strong land-use changes

The application of the concept of ecological networks is often felt to be of great importance in intensively used, multifunctional areas with a high population density, and resulting high social and economic value of the land. The examples in agricultural dominated lands as well as urbanized areas make this evident. However, it is becoming clear that also in regions where the bio-diversity is still high, but where developments regarding land-use changes are strong and foreseeable for the near future, the planning of ecological networks is important as a guidance for these land-use changes. A study, regarding this problem focused at the Yungas in Argentina (Somma 2006).

The land-use changes in the Yungas area result in a continuous and massive process of deforestation. Most important factors for these land-use changes are the growth of farmland, new infrastructure and the establishment of new housing areas. The main

driving forces for new farmland are the increased demand (globally) for crops such as soy-beans, sugarcane and corn, crops for which high potential soils are available in the study area. It has already led to a deforestation of 80.000 ha of land during the last 25 years in the Yungos area, while the expectations are that this process will accelerate even more because of the worldwide increasing demand for bio-fuel-crops.

The basic assumption of the research was that these land-use changes are inevitable, and ecological corridors or buffer-zones, to connect the remaining nature reserve areas should be developed along with the changing land use. Therefore, an optimal balance needs to be found between the future land use and the quality of the connecting zones. The research is based upon a model of territorial planning as given in Figure 4.

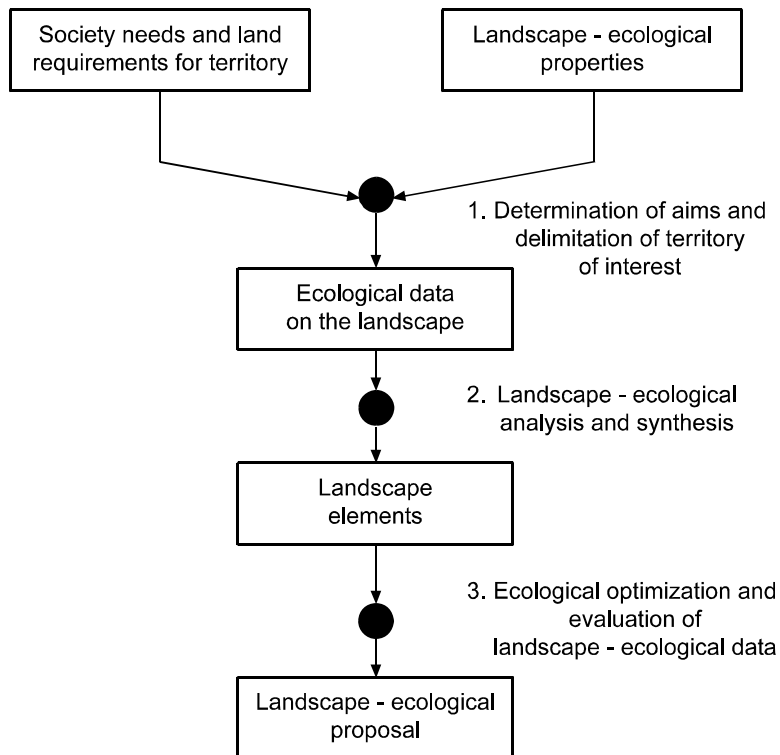


Figure 4. Model of territorial planning (according to Ruzicka and Miklos 1990).

The approach is based on two principal studies: a time series analysis of land-use changes (with specific attention of deforestation), together with its effects on wildlife habitat availability and landscape connectivity; and a planning response, in terms of a set of biological corridors, linking the parks. For the land-use changes a conceptual model was followed which, in a simplified way, looks as the model presented in Figure 5.

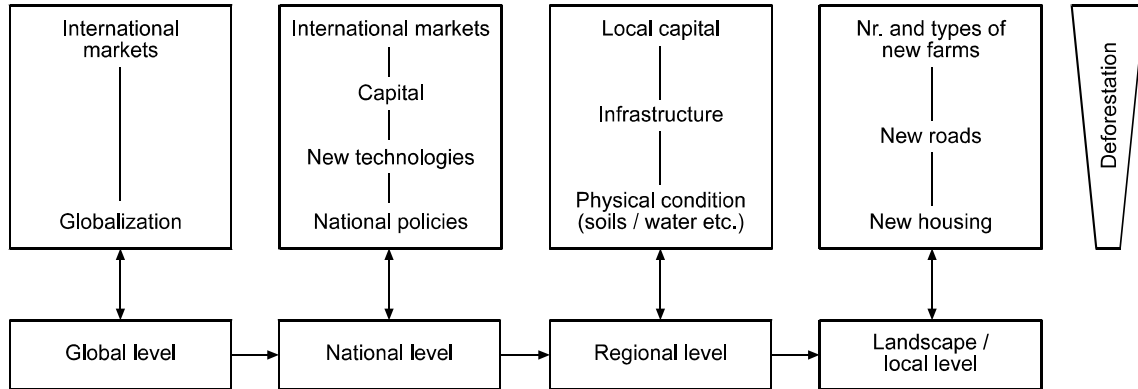


Figure 5. A simplified version of the LUCC-model (after Somma 2006).

The design of a landscape connectivity structure is based upon the study of the habitat conditions for focal species. In his study Somma (2000) focused partly on the Ocelet (*Leopardus Pardalis*) but especially on the Jaguar (*Panthera Onca*). The final habitat quality model for the jaguar was based on a logistic regression between presence data and possible explanatory variables such as the distance to temperate montane forests, the distance to montane subtropical forests, natural variables (rivers, vegetation) and human variables (roads, population density, distance to farmland).

The next step in the study was the design of biological corridors. This was done by evaluating the landscape connectivity at regional scale, using the jaguar habitat model. This evaluation focused on vulnerability: conflict areas in association with possible land-use conversions, the results of which were included in the corridor design. Figure 6 gives some results regarding the relevant patches.

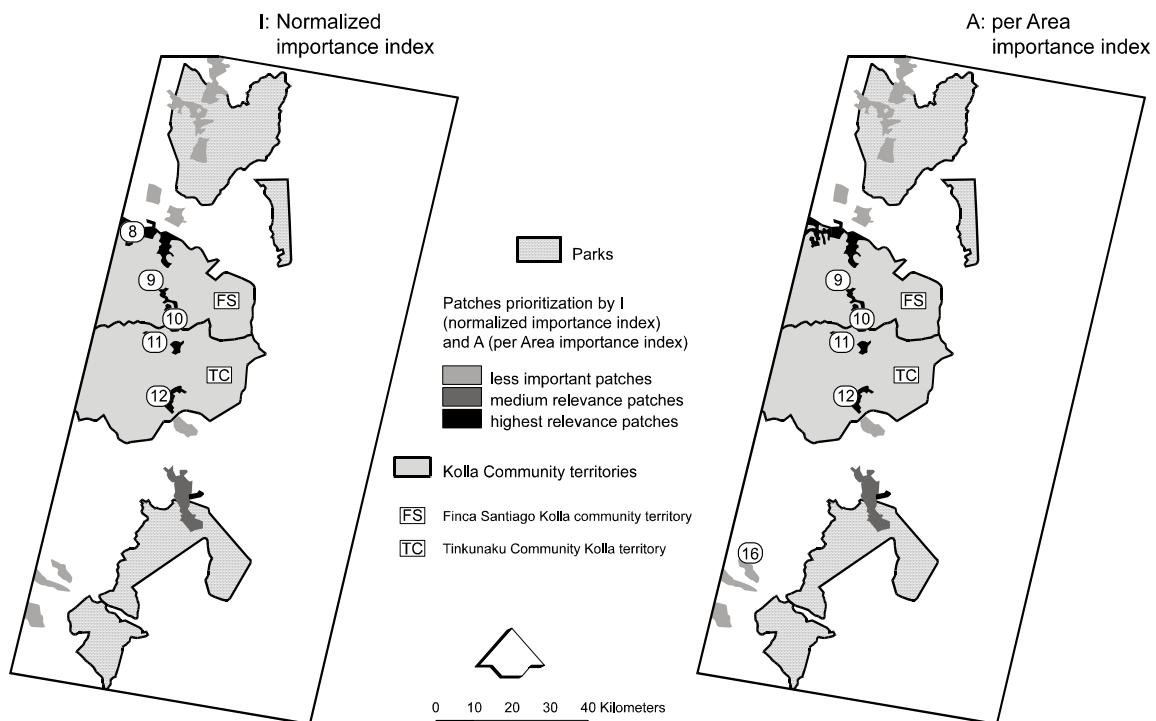


Figure 6. Relevant patches in the Yungos areas, as a basis for the connections of the parks (Somma 2006).

The last step in the process was using scenarios for alternative futures, by giving priority to different interest groups. The use of alternative scenarios provided a platform for involving stakeholders in this part of the process. This allowed the modeling of three possible scenarios for the expansion of farmland; different configurations of wildlife habitats and alternative landscape connectivity. Figure 7 shows the three alternative scenarios.

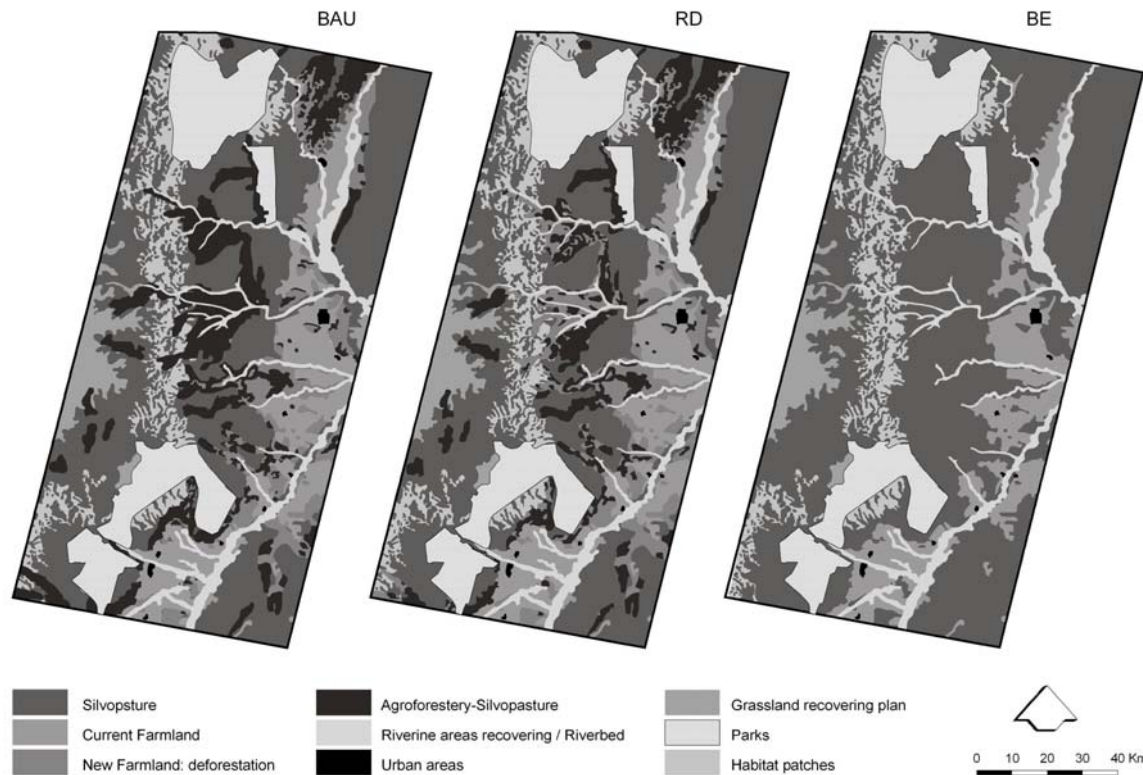


Figure 7. The results of a connective zone between the parks for three scenario's (BAU: 'Business As Usual'; RD: 'Regional Development' and RE: 'Biodiversity and Ecotourism') (Somma 2006)

The results showed large differences between the scenarios with respect to the size, location and quality of the connectivity between the parks. As might be expected, the 'business as usual' scenario resulted in the worst quality. From the research was concluded that only a conscious steering of the land-use changes will guarantee a high quality ecological infrastructure.

4 Retrospect

The presented cases are not very easy to compare. Each case has its own specific context with respect to the type of region, its development-stage and its political and socio-economic situation. However, in each of the cases the physical and spatial conditions of the area as well as the dynamics in the region showed to be important issues. In the case of the Yungas-study Somma (2006) concluded that 'a more integrated, multi level approach to the analysis of the land-use-changes process could give more flexibility and capacity to face the dynamics'. These dynamics can be great

and of several types. Esbah and Cook (2007) are in this regard mentioning: new near nature areas, new synthetic corridors (railways, roads, canals), new golf yards and recreational networks.

The case studies indicate that the use of the ecological network concept as a tool for land use planning proves to be a viable approach to create a new basis for future land uses, and might support the balancing of economical development and environmental protection. Opdam et al. (2006) come to a similar conclusion. They argue that using ecological networks are a prerequisite for ecological sustainability in human-dominated landscapes. However, they conclude that linking ecological sustainability to economic and social sustainability of the landscape will require an extension of the ecological network concept with other sustainability indicators (see also Termorshuizen et al. 2006). Consequently, the added value for e.g. human health, recreation, housing, but also the planning process itself should be clarified (Opdam et al. 2006). In an extensive research to design sustainable landscapes in several case studies in Kenya, through a process of participatory planning and reflective learning, Duchart (2007) comes to the conclusion that where 'the landscape system (is) the object of study, the landscape-design approach and the form and use of green networks (as a spatial concept) to build sustainable environments, remain core issues within the applications'.

In a recent study on the application of spatial reserve network design, van Teeffelen (2007) distinguishes three main questions that have to be solved: (1) What to conserve?, (2) Where to conserve?, and (3) How to conserve? Van Teeffelen concludes that with respect to the 'what' question we have to rely on biodiversity surrogates and clear goals need to be set, resulting in a prioritizing of species and the resolution of how much needs to be conserved. The 'where' question deals with site selection problems. According to van Teeffelen (2007) small site selections with few species can be solved by hand, but 'conservation planning (problems) typically encompass large areas and many species, for which finding efficient and effective solutions is not longer straightforward'. Finally, the 'how' question concerns the process of implementation, and the methods, policies and instruments to bring about the wanted situation, including restoration, protection and specific management practices.

With regard to the planning aspects of ecological corridors – the real creation - there are remarkable differences between the nations. Countries with a long tradition of land-use planning (e.g. through national or regional plans) or with specific types of planning (e.g. land redevelopment plans) are ahead of those countries with no or a little experience in this regard. As Somma (2006) makes clear, the next step in the process is: planning. Or even better: the next step is to incorporate studies, research and design of ecological corridors as an integral part of the whole process. Cook (2000) concludes that 'the problems of land-use intransigence, political and jurisdictional issues create a difficult environment for implementing ecological networks'. In his view there are clear differences between Europe and North America. As he puts it: 'In North America, and in particular the Western United States, planning authority rests with individual municipalities, making planning at landscape or regional scale difficult'.

The design of an ecological network that is not imbedded in a political-planning process is likely to fail. The majority of the researches performed are merely desk studies. They are in no way part of a (participatory) planning process. How thorough and well-funded the study may be and how good the design-work is done, at best they may get some attention later-on in e.g. a regional development plan. No doubts the final results will be poor. Is it not the most important conclusion that can be drawn from the many and different studies regarding the design of ecological networks so far, that their successes will depend on the possibility to create a political and jurisdictional basis for land-use planning?

References

- Ahern, J. (2002). *Greenways as strategic landscape planning: theory and application*. Dissertation, Wageningen University.
- Aitken, W.R.O. (1988). *The environment and the economy*. Centre for Resource Studies Special Paper. Kingston: Queens University.
- Arts, G.H.P., van Buuren, M., Jongman, R.H.G., Nowicki, P., Wasscher, D., & Hoek, I.H.S. (Eds.) (1995). Ecological networks. *Landschap*, 12(3), Special Issue, 130 p.
- Bischoff, N.T. & Jongman, R.H.G. (1993). *Development of rural areas in Europe: The claim for nature*. Netherlands Scientific Council for Government Policy. The Hague: SDU.
- Bryden, J.M. (1994). Some preliminary perspectives on sustainable rural communities, In: J.M. Bryden (Ed.), *Towards Sustainable Rural Communities: The Guelph Seminar Series*. (pp. 41-50). Guelph: University of Guelph, School of Rural Planning and Development.
- Cook, E.A. & van Lier, H.N. (Eds.) (1994). *Landscape planning and ecological networks*. Amsterdam: Elsevier.
- Cook, E.A. (2000). *Ecological networks in urban landscapes*. Dissertation, Wageningen University.
- Csuti, B., Polasky, S., Williams, P.H., Pressey, R.P., Camm, J.D., Kershaw, M., Kiestler, A.R., Downs, B., Hamilton, R., Huso, M., & Sahr, K. (1997). A comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. *Biological Conservation*, 80, 83-97.
- Duchart, I. (2007). *Designing sustainable landscapes. From experience to theory. A process of reflective learning from case-study projects in Kenya*. Dissertation, Wageningen University.
- Esbah, H., & Cook, E. (2007). Effects of urban landscape change on open space preserves. In Print.
- FAO (1993). *Guidelines for land-use planning*. Rome: Food and Agricultural Organization of the United Nations.
- Forman, R.T.T. (1995). *Land mosaics: the ecology of landscapes and regions*. Cambridge: Cambridge University Press.
- Hanski, I. & Gilpin, M. (Eds.) (1997). *Metapopulation biology; ecology, genetics, and evolution*. San Diego: Academic Press.
- Kerkstra, K. & Vrijlandt, P. (1990). Landscape planning for industrial agriculture: A proposed framework for rural areas. *Landscape and Urban Planning*, 18, 275-287.
- Leitão, A.B. & Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning*, 59, 65-93.
- Levins, R. (1970). Extinction. In: M. Gerstenhauber (Ed.), *Some mathematical questions in biology, (Vol. 2) Lectures on mathematics in life sciences*. Rhode Island: American Mathematical Society, Providence.
- Linehan, J.R., Gross, M. (1998). Back to the future, back to basics: The social ecology of landscapes and the future of landscape planning. *Landscape and Urban Planning*, 42, 207-224.
- MacArthur, R.H., & Wilson, E.O. (1967). *The theory of island biogeography*. Princeton: Princeton University Press.
- Margules, C.R., Nicholls, A.O., & Pressey, R.L. (1988). Selecting networks of reserves to maximise biological diversity. *Biological Conservation*, 43, 63-76.
- Matthysen, E. & Currie, D. (1996). Habitat fragmentation reduces disperser success in juvenile nuthatches *Sitta europaea*: evidence from patterns of territory establishment. *Ecography*, 19, 67-72.
- Matthysen, E., Adriaensen, F. & Dhondt, A.A. (1995). Dispersal distances of nuthatches, *Sitta Europaea*, in a highly fragmented forest habitat. *Oikos*, 72, 375-381.
- National Task Force on Environment and Economy (1987). *Report of the national task force on environment and economy*. Winnipeg: Canadian Council of Resources and Environment Ministers.
- Oostindie, H., Roep, D. & Renting, H. (2006). Definitions, references and interpretations of the concept of multifunctionality in The Netherlands. In: P. Caron and T. Le Cotty (Eds.), A

- review of the different concepts of multifunctionality and their evolution, European Series on Multifunctionality No 10* (pp. 41-81), France: Cemagref.
- Opdam, P., Steingröver, E., & van Rooij, S. (2006). Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. *Landscape and Urban Planning*, 75, 322-332.
- Ruzicka, M. & Miklos, L. (1990). Basic premises and methods in landscape ecological planning and optimization. In: I.S. Zonneveld & R.T.T. Forman (Eds.), *Changing Landscapes: An Ecological Perspective* (pp. 233-260) New York: Springer-Verlag.
- Science Council of Canada (1989). *Environmental peace keepers: Science Technology and Sustainable Development*. Ottawa: Science Council.
- Smith, D.S. & Hellmund, P.C. (Eds.) (1993). *Ecology of greenways. Design and function of linear conservation areas*. Minneapolis: University of Minnesota Press.
- Somma, D.J. (2006). *Interrelated modeling of land use and habitat for the design of an ecological corridor. A case study in the Yungas, Argentina*. Dissertation, Wageningen University.
- Steiner, F. (2000). *The living landscape: An ecological approach to landscape planning*. New York: McGraw Hill.
- Termorshuizen, J.W., Opdam, P. & van den Brink, A. (2006). Incorporating ecological sustainability into landscape planning. *Landscape and Urban Planning* 79, 374-384.
- van Buuren, M. (1991). A hydrological approach to landscape planning: The framework concept elaborated from a hydrological perspective. *Landscape and Urban Planning* 21, 91-107.
- van Buuren, M. & Kerkstra, K. (1993). The framework concept and the hydrological landscape structure: a new perspective in the design of multifunctional landscapes, In: C.C. Vos and P. Opdam (Eds.), *Landscape ecology of a stressed environment* (pp. 219-243). London: Chapman and Hall.
- van Dorp, D. & Opdam, P.F.M. (1987). Effects of patch size, isolation and regional abundance on forest bird communities. *Landscape Ecology*, 1, 59-73.
- van Langevelde, F. (1999). *Habitat connectivity and fragmented nuthatch populations*. Dissertation, Wageningen Agricultural University.
- van Langevelde, F., van der Knaap, W.G.M., & Claassen, G.D.H. (1998). Comparing connectivity in landscape networks. *Environment and Planning B*, 25, 849-863.
- van Langevelde F., Schotman, A., Claassen, F. & Sparenburg, G. (2000). Competing land use in the reserve site selection problem. *Landscape Ecology*, 15, 243-256.
- van Lier, H.N. (1994). Focus on land use: A comparative study of three regions in Europe as a basis for land-use planning, In: L.O. Fresco, L. Stroosnijder, J. Bouma and H. van Keulen (Eds.), *The future of the land. Mobilising and integrating knowledge for land use options* (pp. 137-138). Chichester: Wiley.
- Van Teeffelen, A.J.A. (2007). *Where and how to conserve: Extending the scope of spatial reserve network design*. Dissertation, Helsinki University.
- Verboom, J. (1996). *Modeling fragmented populations: Between theory and application in landscape planning*. Wageningen: IBN Scientific Contributions 3.
- Verboom, J., Schotman, A., Opdam, P., & Metz, J.A.J. (1991). European nuthatch metapopulations in a fragmented agricultural landscape. *Oikos*, 61, 149-156.
- Vos, C.C., Verboom, J., Opdam, P.F.M., ter Braak, C.J.F. (2001). Towards ecologically scaled landscape indices. *The American Naturalist*, 157, 24-41.