Green Corridors in Central Israel: A GIS Analysis of Alternative Spatial Configurations

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The use of a GIS-based method for determining ecological cores and corridor routes is described. Least environmentally disturbed corridors were delineated using standard database and ARC/GRID least-cost path functions. Progressive analysis taking into consideration historic and archeological values, width, existence of bottlenecks, types of connections and regional functioning is discussed. Two wide corridors, representing an agricultural ring with a low-density village pattern surrounding a central rural zone, are suggested for landscape conservation of this region. The National Outline Plan 35 (NOP35) defined general definitions of ecological networks elements. According to these definitions the described GIS approach enables the delineation of relatively large-scale corridors with precise contour lines. It is suggested that it be applied gradually to the entire country for progressive land use planning and to forward planning from the theoretical to the practical stage.

Keywords: Human-dominated landscapes, landscape fragmentation, ecological networks, connectivity, core areas, green corridors, GIS analysis.

Land use transformations due to population growth and air, soil and water pollution have resulted in severe land degradation worldwide. Loss of plant and living species, decreased biodiversity, fragmentation of ecological systems and rural landscape transformation are among the primary repercussions of such degradation. In 1992, the UN Conference on Environment and Development (UNCED) in Rio de Janeiro called for firm action to protect natural environments on both the local and the global scale. The creation of Ecological Networks and Greenways has been recognized as an important measure for halting the deterioration of natural ecosystems (Jongman, 2001; Jongman, 1995). Perspectives and concepts of ecological networks can be found in Cook and van Lier (1994) and Nowicki et al. (1996). Several broad regional programs have been initiated in Europe, including the PanEuropean ECOnet Project within the framework of the European Commission's Life Environment Program initiated in 1999 (Liro, 1995; Sabo and Cárska, 1997; O'Riain, 2001) and the Greenways/Parkways in the USA and Australia.

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Israel's population density is among the highest in the developed world where only Japan, Holland, and Belgium are as crowded (ARIGA, 2001). Moreover, Israel's population continues to grow faster than any developed country—at a rate of 2% annually (ARIGA, 2001). According to rates of land transformation recorded during the past 50 years, Israel is expected to deplete almost all of its natural ecosystems within 100 years (Mazor, 1993; Shoshany and Goldshlager, 2002). In view of these trends, the integrated National Outline Plan 35 of Israel (NOP35; Asif and Shachar, 1998) was established, among other concerns, to deal with the habitat fragmentation threat. It has defined a north to south 'green avenue' and east to west green buffer zones or corridors that would serve connectivity of national and regional scales for the long run. These elements were only defined in a general way (1:500,000-scale map). The formation of the actual 'green avenue' and corridors and legislation of their status requires detailed planning. This should be based on updated and detailed information regarding land uses and habitat conditions. Geographical Information Systems (GIS) provide cost effective tools for the analysis of patterns, assessment of alternatives and delimitation and monitoring of the green corridors.

The aim of this study was to develop a GIS method to delineate and evaluate alternative potential plans of green corridors in a detailed manner. Corridors in the study context are delineated to preserve natural habitat as well as to optimize the quality of human environment. Thus, while most studies consider species-specific biological needs our approach was to base corridor delineation on land-use/cover data to utilize a wider view suitable for human-dominated landscapes. A second objective was to implement these techniques for an area in central Israel, south of Tel Aviv metropolitan area, representing countrywide rural patterns.

ECOLOGICAL NETWORKS CONCEPTS

Human modification of landscape reduces connectivity between natural habitats (Beier and Noss, 1998). Many conservation biologists agree that habitat fragmentation threatens biological diversity and is a primary cause of many species extinction phenomena (Noss, 1987). Ecological networks involve connecting patches of otherwise isolated habitats. Despite the debate around this strategy (Simberloff and Cox, 1987; Simberloff, et al., 1992; Mann and Plummer, 1995) many ecologists and conservation activists argue that ecological networks are critical to maintain biodiversity and save many endangered species. By reviewing empirical papers about corridors connectivity potential Beier and Noss conclude '...that well-designed studies generally support the utility of corridors as conservation tools...' and they '...provide benefits to or are used by animals in real landscapes' (Beier and Noss, 1998:1249).

Aims

There are two approaches to the development of ecological networks. These reflect differences in emphasis rather than in the broad view. One approach concentrates on bio-diversity. Its essence is formation of a spatially integrated network of areas least transformed by man and which, at the same time, reflect the variety of nature. Its aims are as follows (Liro, 1995; Sabo and Cárska, 1997; O'Riain, 2001):

- Protection of species and habitats listed as particularly endangered and considered to be of special importance;
- Formation of migration routes vital both for the preservation of genetic variety and, in many cases, for the survival of populations.

Noss (1987) presents a synergetic approach, which considers ecological factors as well as social and economical ones. It can be regarded as 'more-practical' in human dominated landscapes. According to this approach ecological networks aims at providing physical conditions for maintaining ecosystems in a landscape that to a certain extent is also exploited by human activities. In these mixed environments most existing reserves are far too small to maintain natural ecological processes and larger ones would not necessarily kept as such. Noss states that in real-life landscapes the connectivity strategy '...can be a cost-effective *complement* to the strategy of preserving large and multiple reserves' (Noss, 1987:162). Such designed ecological networks have also anthropocentric functions of maintaining 'open-spaces' in developed landscapes and protecting cultural heritage areas and for recreation (AFER, 1998). With this attitude biologists and planners can work together to develop local ecological network designs '...that can optimize the quality of both the human and nonhuman environment' (Noss, 1987:162). One of the possible combinations facilitating this aim is between organic farming, low intensity tourism and conservation of natural ecosystems.

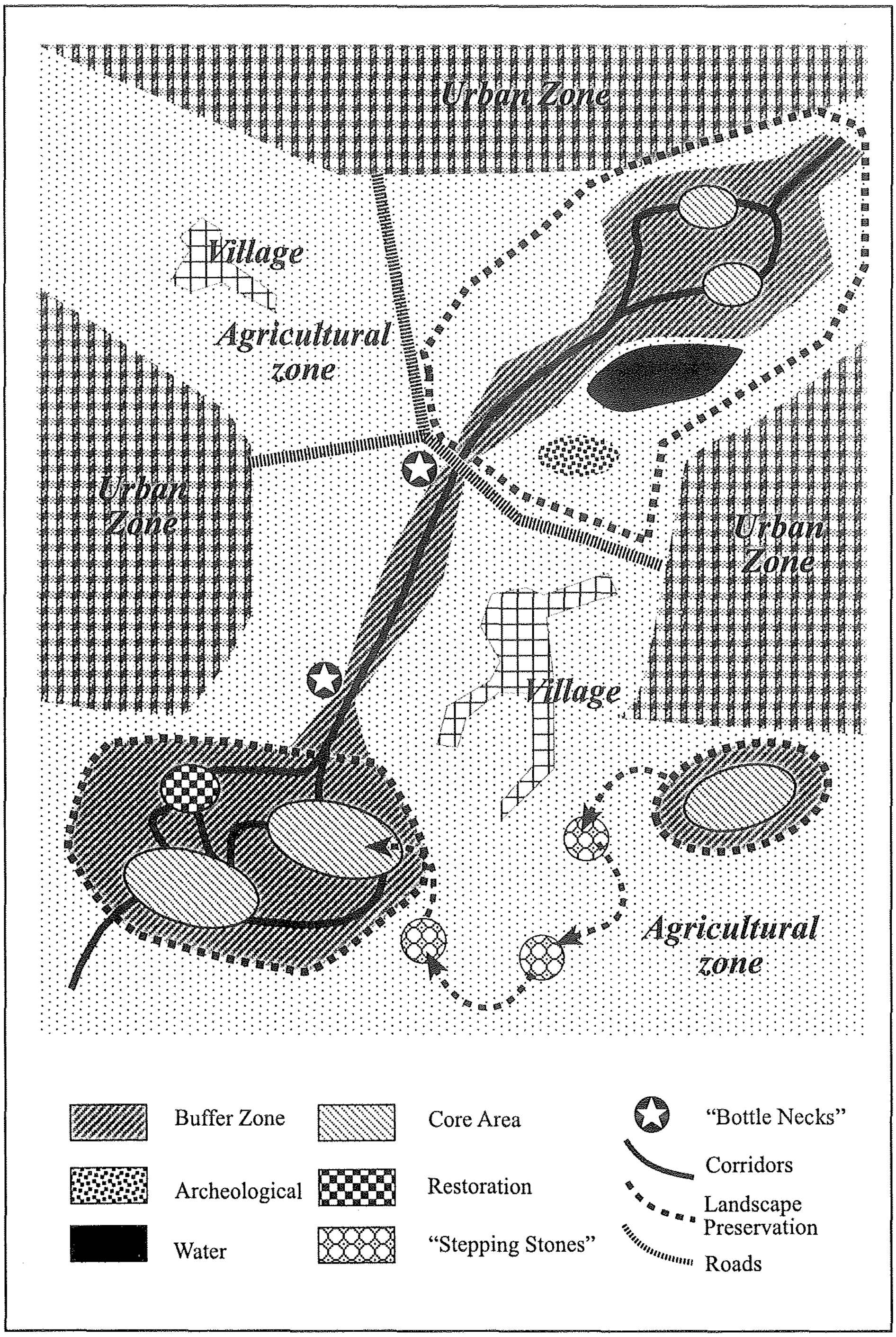
Structure

Ecological networks are typically structured around the following elements (Figure 1):

Core areas: These are areas of high ecological and/or landscape significance, which have been recognized at the national level. In the case of natural core areas, they will consist of habitats maintaining rare or near-extinct species or areas with exceptionally rich biological diversity. Core landscape areas mainly represent a composite of natural, traditional and cultural land-use systems, while their importance lies in their interactivity.

Corridors: These are elongated territories of natural vegetation, which provide important habitats for wildlife by connecting between core areas (Rosenberg et al.,

Figure 1: General scheme of elements of ecological networks.



1995). These connectivity elements were originally suggested by Wilson and Willis (1975) based on equilibrium theory of island biogeography. According to this theory corridors raise species diversity in core areas, which they are connected to, by increasing immigration rate (Simberloff and Cox, 1987; Simberloff et al., 1992). In the synergetic approach on the other hand, corridors may be designed also to maintain or restore natural and semi-natural landscape connectivity for ecological as well as for quality-of-life concerns (Noss, 1987).

These areas may have varying shapes:

- Linear strips allow the flow of resources and bio-directional migration between core areas. The most common corridors of this kind are rivers/streams connecting between habitats. These corridors often follow both roadless and partially developed areas. Other physical corridors could be formed by natural barriers such as stretches of bare rocks or cliffs or by artificially creating boundary features such as hedges and windbreakers.
- Narrow linear zones of continuity of ecosystem or landscape types that connect core areas of the same type. Examples of this type are forest strips connecting large forest areas; water flows connecting lakes; a strip of crop fields connecting agricultural areas.
- A linear pattern of 'stepping stones' arranged within distances that enable migration between core areas, though without physical continuity. In a discontinuous landscape, these stepping-stones could be connected by elements symbolizing association with neighboring core areas.

Nature restoration areas: These are areas in which important core areas have been degraded due to air/soil/water pollution, or due to overuse or recurrent disturbances, while their former values could be restored by implementing an ecological management policy. In many cases restoration requires the allocation of financial resources for removing pollutant sources, changing land uses, in parallel to the application of administrative rules and legislation.

Core size and corridor width

As landscapes are fragmented into small patches of habitats it is important to determine the minimum area needed to allow species survival to an acceptable level (Beier, 1993). Beier states that the minimum habitat or core area, determined for species population in the USA, lies between 25,000 and 55,000 hectares with no immigration corridor and may be 5,000–15,000 hectares smaller with an immigration corridor (Beier, 1993). These figures show the significant contribution of the existence of linkage corridors in habitat preservation design. Nonetheless, these figures vary because of different species-specific needs and different biological and environmental conditions. Researchers of the synergetic approach came up with much smaller minimum core size. According to the framework of the PanEuropean

ECOnet (Liro, 1995), these areas should not be smaller than 500 hectares. Weber and Wolf (2000), relying on their work in Maryland (USA), suggest that statewide core areas should be at least 809 hectares; while local areas should range from 202 to 809 hectares. Both studies relate to areas greatly different from Israel regarding population reproduction and density. However, these figures are also the acceptable minimum core size in Holland (Jongman, per. comm., 2002), which is a densely populated country as well.

As with core size corridor width has in most cases a functional role (Noss, 1987; Lindenmayer and Nix, 1993). Generally speaking, corridors should be as wide as possible. In reality the necessary width will vary significantly depending on habitat structure; particular species that we expect to use the corridor and their needs; ecological quality within the corridor; the nature of the surrounding habitat; and the human use patterns (Noss, 1987; Beier and Loe, 1992; Truan and Kampbell, 1998). Still, there are some general suggestions for an acceptable corridor width most of them relate to the synergetic approach. The width of a corridor should be between 500 meters and several kilometers according to the framework of the PanEuropean ECOnet (Liro, 1995). Based on their experience in Maryland, Weber and Wolf suggested that: 'Where corridors followed streams, streams were buffered 168m on each side, giving 15m of interior conditions and 152m of transition to edge on either side...Where corridors were not along streams, the least-cost path was buffered a distance of 168m' (Weber and Wolf, 2000:265).

Ecological Networks Design

Ecological networks in human landscapes might be preserved in the long run within a land-use hierarchy, which forms the necessary environmental conditions required for their sustainability and for minimizing disturbances. This hierarchy could be represented by the following sequence: natural reserves, parks and/or plantation areas, semi-natural areas (with controlled grazing and recreation intensities), crop fields and orchards, rural zones, low density residential areas, and finally urban zones and commercial and industrial areas. National planning must therefore ensure the following:

- Core and corridor areas are surrounded by buffer zones protecting them from sources of disturbance and pollution;
- Conservation/development conflicts at the vicinity of core/corridor are prevented or reduced; and
- Future land-use changes will not significantly increase the fragmentation of the ecological network.

Integration of both top-down and bottom-up approaches is required for reaching these objectives. Core areas will then be delineated by combining elementary landscape units and buffer areas. Certain land-use preservation and management policies will then be applied to regions containing and linking important core areas. A network of these regions will form the national system of open landscapes composed of natural, semi-natural, agricultural and rural zones. Another aspect of crucial integration is gained by ensuring that the structuring of the ecological network within a certain region will also benefit the local society, as implied by Noss (1987).

GREEN CORRIDORS IN ISRAEL WITHIN THE FRAMEWORK OF NATIONAL OUTLINE PLAN 35 (NOP35)

The Integrated National Outline Plan for Construction and Development number 35 (NOP35) Asif and Shachar, 1998) is a countrywide land-use plan in its final legislation stages. It aims at forming a long-term national planning framework for residence and employment taking into account physical, social, economical and environmental aspects. Land reserve formation for residence, infrastructure and employment is a major concern, and must be planned carefully to ensure the conservation of both the quality of life and natural and landscape values. However, due to a high population density, conflicts over land-uses intensify (Mazor, 1993; Shoshany and Goldshlager, 2002). Land-use allocation must therefore be performed within a wide context taking into account both current and future environmental consequences. The NOP35 is based upon three principles:

1. Structuring the open areas system by forming a 'green avenue' which will maintain continuity of open areas from northern Israel to the south;
2. Strengthening Beer Sheva and Haifa as metropolitan centers in order to prevent the population moving to Tel Aviv metropolitan areas;
3. Formation of east-to-west corridors that connect both built-up regions and open areas in parallel (mainly along stream routes).

The NOP35 is thus based on a search for equilibrium between controlled growth of urban and developed areas and the maintenance of a north-to-south and east-to-west lattice of open areas.

However, it is clear that the development of residential, commercial and industrial areas together with efficient transportation systems connecting them will come primarily at the expense of open and agricultural areas. As a result, 'wildlife habitat and migration corridors are being lost, and normal ecosystems functions such as absorption of nutrients, recharging water supplies and replenishment of soil are being disturbed or destroyed' (Weber and Wolf, 2000:265). In order to minimize irreversible damage, the NOP35 presented a sensitivity map of open areas that may serve as a national plan, taking environmental aspects into account. The open area valuation is determined through a wide view considering their *sensitivity*, *continuity* and *national functioning*. The open area sensitivity process is initiated by the definition of landscape units. These units are defined as elements of remarkable contour lines that have uniform attributes in relation to relief, rock, soil types, climate, and animal and vegetation habitats. Landscape units of cultural/historical significance were also taken into consideration. Evaluation of the defined elements is determined by examining each element's rarity, conservation level, bio-diversity, landscape and visual values, cultural and traditional values, ecological and scientific values, agricultural and hydrological values, and continuity level.

In the framework of the NOP35 it seems that the *continuity* level of the open area elements is drawing significant attention. It derives from the fact that an ecological function value of an open area increases with its size and as a function of how free it is of developed spots. Considering Israel's limited area and the distribution of its infrastructure and transportation networks, open areas with high ecological value have become scarce. In order to avoid further shrinkage of existing open corridors an expansion of the three basic principles was defined by more specific and particular principles:

- Maintenance of strategic buffer zones separating between the major metropolitan areas;
- Conservation of large natural and recreational open areas in the Negev and Galilee for the entire population;
- Identification and prioritization of local core areas that represent high ecological and recreational values for the local population;
- Preservation of east-west corridors along streams that separate between coastal dense cities and function as green lungs for their population;
- Maintenance of high accessibility to the coastline by inland population.

These principles separate between national and local levels since there is a difference between national and local core areas and corridors in relation to ecological value, land-use composite and size.

As a national level plan, the NOP35 forms only a generalized land-use allocation map aimed at guiding local planning rather than forming rigid zoning. The present indecisive/generalized status of the national plan together with the urge for built-up and infrastructure expansion raise two major threats: (a) a rapid loss of land reserves; and (b) penetration of massive development into the 'green avenues' and the ecological corridors. Under these circumstances, it is of prime national concern that detailed analysis of local planning aspect will be carried out. Such analysis could identify the most important corridors allowing the highest level of continuity between natural/recreational/historical core areas.

Implementing the GIS for this purpose will allow objective assessment of alternative corridor configurations and optimal delineation of zones, which must be allocated for landscape conservation and natural restoration. Government planning administrations and local authorities may then choose to adopt these tools for both guiding and monitoring development.

STUDY AREA

It was decided that the study area would be a region located on the margin of the central metropolis and an area with efficient data sources for the corridor delineation process. An updated land cover/use map, created by satellite imagery knowledge-based classification, was available for the two 1:50,000-scale topographic map sheets: Ashdod and Gedera. Figure 2 presents the study area location and outline, and Figure 3 presents a land cover/use map of the area. The area is characterized by relatively homogeneous environmental conditions. It is a plain with a maximal height of 240m. Annual precipitation ranges between 400–500 mm. Over 60 percent of the soils are suitable for agriculture. Since this area functions as a metropolitan margin, it is highly dominated by human landscapes. Cultivated areas are the main land use (over 50 percent) and built-up areas and infrastructure represent approximately one

Figure 2: Location of the study area.

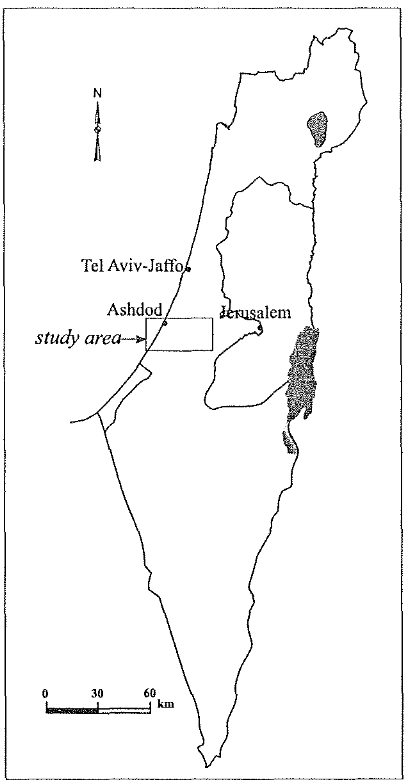
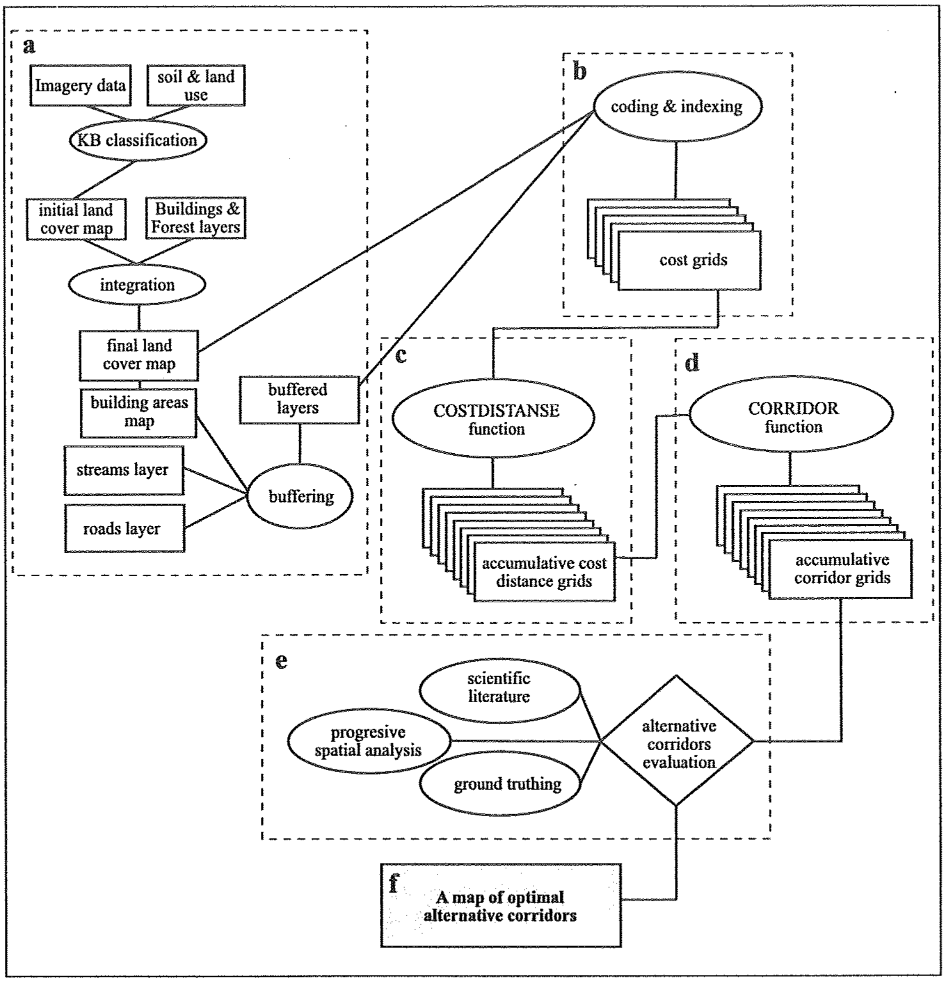


Figure 3: Corridors delineation process.



third of the overall study area. A lack of long-term national landscape design and planning for around 30 years resulted in a scattered pattern of built-up areas all over the country north of the Negev (the southern part of the country). The study area suffers from a scattered pattern of the built-up areas (Figure 3). This pattern divides natural habitats and damages their functionality. Still, relatively wide natural habitats exist on both the eastern and western sides of the study area. The Judean lowland to the east is dominated by shrublands and pine forests, while sand dunes dominate the Mediterranean Sea coast. Narrow semi-natural habitats exist along the four main creeks in this region: Sorek, Barka'i, Ha'elah and Lachish.

METHODOLOGY

Human-dominated landscapes, which dominate the study area, represent an ecological disturbance as a source for air pollution and as barriers preventing wildlife transit. In such a densely populated region, with scattered pattern of developed areas, ecological cores and corridors allocation and values can be determined by considering levels of ecological disturbance. Modeling human-dominated landscape with respect to environmental values was achieved by dividing it into two main types: built-up and cultivated areas. Built-up areas are considered permanent ecological disturbances. Their destruction could also greatly change the environmental values of their area and the value of a particular corridor route. On the other hand, cultivated areas are considered less disturbed, since they may recover and return to their initial natural habitat if abandoned or if confiscated and restored by planning authorities.

Although the study area is dominated by human landscape there are still relatively wide open areas in its eastern and western sides and narrow semi-natural habitats, which exist mainly along stream channels. These habitats represent highly valued connective corridor routes between the natural cores in the eastern and western sides. Indeed, there is evidence that jackals *(canis aureus),* for example, transit from east to west along the main stream channels in this area. Expansion of residences, infrastructure and factories may permanently damage these scarce corridors. This situation necessitates a detailed delineation of corridors passing through least disturbed areas.

Under this division we delineated corridors offering optimal connectivity along least disturbed habitats between six chosen natural habitat cores. We assumed that even though corridors of pure natural habitats are rare in the study area, precise delineated semi-natural and agricultural corridor routes are crucial for the enforcement of the NOP35 regional environmental planning decisions.

Our approach offers an assessment of alternative corridor routes by examining generalized types of rural landscape and their internal relationships. Following Walker and Craighead (1997), we used the least-cost path tracing as a means of estimating the connectivity level of alternate routes. The least-cost path technique, when based upon environmental assumptions, grades paths (a path can be defined as a group of connected line-like cells) between core areas according to their disturbance level and thus enables effective corridors localization and grading. The least-cost path balances habitat suitability, distance and degree of 'connectivity' between the two core areas (Walker and Craighead, 1997). The flowchart in Figure 3 describes the general process of corridor delineation map extraction. It presents six main phases:

1. Data gathering and database construction;
2. Generation of various cost grids;
3. Generation of accumulative cost distance grids (COSTDISTANCE function);
4. Generation of alternative corridor grids (CORRIDOR function);

5. Evaluation of alternative corridors; and
6. Drawing optimal corridors map.

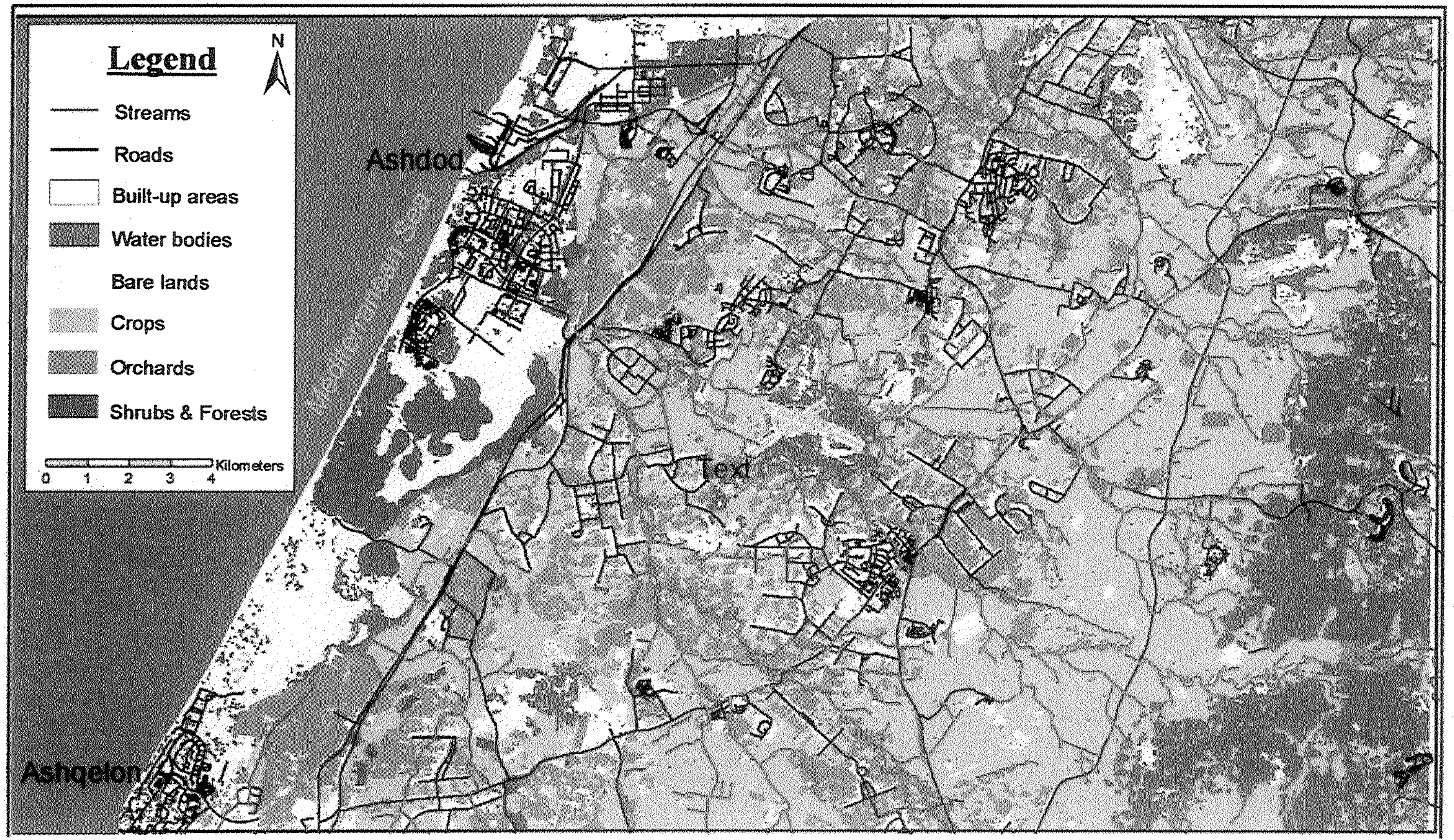
The following paragraphs present a detailed description of the methodology in a logical order rather than a chronological order.

Data Gathering and Database Construction

Data gathering and database construction are critical phases for a qualitative corridor delineation process. Appropriate environmental indicators are used for specifying least disturbed connectivity routes. Four generalized indicators were determined for cost evaluation:

1. **Land cover/use layer:** Land cover/use affects the ecological value in relation to core determinations and tracing the best corridors between them. Using PCI and IMAGINE software, Landsat TM multi-temporal imagery data, a soil layer from the GIS of the Ministry of Agriculture of Israel and a land use layer from the Israeli National GIS were combined into the knowledge-based classification to extract an updated land cover/use map (Figure 4; Cohen and Shoshany, 2001). This map was improved by integration of built-up areas and the water body layer from the Israeli National GIS and the forest layer from the GIS of the Jewish National Fund (JNF KKL) GIS. The final map is grouped into 6 classes: built-up areas, water bodies, bare lands, crops, orchards, and shrubs and forests. Boundaries of natural resorts, national parks, and valuable archeological sites were digitized on a separate layer and combined with the land cover/use map.
2. **Proximity to stream channels:** Stream channels and their proximate buffer zone generally represent natural/semi-natural habitats and transit paths for wildlife. For this reason they are highly valued for ecological corridor delineation. The main stream channels in the study area were extracted from the hydrology layer of the Israeli National GIS. Correction of main stream channels was necessary and was performed using ArcView software. Proximate zones of main stream channels were extracted by a buffer function with 100m intervals. The resultant buffered shapefiles were rasterized into a grid format for progressive processing using ArcInfo software.
3. **Distance from roads:** Roads and railways have a negative ecological effect. Roads are considered a source of air pollution and noise that fragment natural habitats and destroy the transit of wildlife. However, their negative ecological effect decreases with distance. Roads and railway lines were extracted from the road layer of the Israeli National GIS. As with stream channels main roads and railways were first corrected, buffered and rasterized using ArcView/Info softwares.

Figure 4: Study area—land cover/use map.



4. **Distance from built-up areas:** Built-up areas, as roads and railways, represent highly disturbed areas. Since the building layer was not complete and updated, the building layer from the Israeli National GIS and the developed area cells from the land cover/use map were integrated for all settlement areas extraction.

Least-Cost Corridor Extraction Process

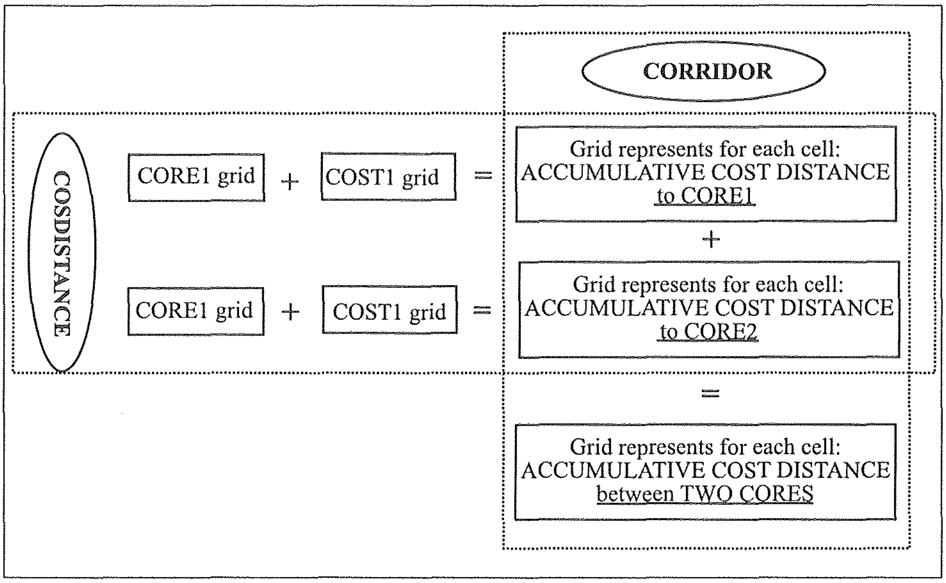
Extraction of least-cost corridor routes was facilitated by the ArcInfo GRID functions COSTDISTANCE and CORRIDOR. Description of the two functions is based on ArcInfo help documents. The COSTDISTANCE function determines the least costly path to reach a source for each cell location. The output grid tells 'how much it would cost each cell to return to a source via the least-cost path' (ArcInfo help). This grid is called *an accumulative cost grid.* Based on two accumulative cost grids, each for different source or sets of sources, the CORRIDOR function 'calculates for each cell location the *sum* of the cost distances for the two input accumulative cost grids and thus identifies the least-cost path from one source to another' (ArcInfo help). The general term 'source' can be replaced with 'core area' in ecological networks context. Figure 5 demonstrates the relationships between the two functions by presenting input and output files of each.

Generation of cost grids and accumulative cost distance grids

The COSTDISTANCE function requires a *core grid* and a *cost grid.* The core grid in an ecological corridor-tracing context identifies ecological cores to which least accumulated cost distance for every cell is calculated. Corridors in this research were aimed at connecting between the natural areas on the Judean lowland to the east and the coastal dunes to the west. Accordingly, four cores were located on the shrub and forest areas in the Judean lowland and represented the eastern core grid. Two more cores were located on the Shita Malbina and Ashdod-Nitsanim natural reserves and represented the western core grid. Five cores exceeded the size of 500 hectares, which is the generally accepted size for core areas in worldwide ecological networks concepts and implementations. The area of the Shita Malbina natural reserve is smaller than the minimal core size (around 440 hectares). However, since it is under conservation it was decided to include it within the western core grids to form core continuity.

The cost grid for each cell determines its environmental cost value and is generally the result of a composite of multiple grids representing environmental indicators. As the environmental value allocated to a cell decreases, in each cost grid, the cost value increases. Thus, the least-cost path should follow low level disturbed areas. Environmental cost grids were calculated based on the following considerations:

Figure 5: Input and output files of COSTDISTANCE and CORRIDOR functions.



land cover/use type; proximity to stream channels; distance from built-up areas; and distance from roads. Cost grids were generated in three steps:

1. Coding: Each layer was divided into three environmental levels: high, medium, and low. Table 1 presents the grading criteria for each layer and the level value given to each cell accordingly
2. Difference enhancement: In order to enhance the difference between environmental levels, each cell value was raised to the second order:

$$\text{cost\_grid} = X_i^2$$

Where X is the cell value (1–3) in layer i.

Cost grids that represent composites of all layers were calculated by calculating the sum of coded values of the different layers:

$$\text{cost\_grid} = \sum_{i=1}^{4} W_i X_i^2$$

Where W_i is the weight given to layer i.

3. Multiplication by cell size: Using the COSTDISTANCE function the cost value assigned to each cell is the cost assigned to the cell in the cost grid multiplied

by the cell size. In order to reduce the effect of the accumulative distance on the calculated accumulative cost value each coded value was multiplied by 10, which is the grid cell size in meters:

$$\text{cost\_grid} = 10 \cdot X_i^2$$

or

$$\text{cost\_grid} = 10 \cdot \sum_{i=1}^{4} W_i X_i^2$$

Table 2 presents eight different cost grid types generated in order to examine various ways for corridor delineation and their different effects. There are four cost grids for each individual layer (R1–R4), one cost grid, which represents a composite of all four layers without weigh (R5), and three cost grids, which also represent composites of all four layers but with triple weight given to proximity to stream lines (R6), distance from built-up areas (R7) and distance from roads (R8). It can be seen that since low values represent a high environmental value the triple weight given to a certain layer was obtained by duplicating all other three layers in the three integrated cost grids.

Table 1: Cost grid calculation—Step 1: dividing each layer into three environmental levels and coding cell values accordingly.

Layer	*Type/Value*	*Level*	*Cell Value*
Land-cover/use type	Natural reserves, national resorts, archeological sites, shrublands and forested areas.	High	1
	Crops, orchards, bare lands.	Medium	2
	Water bodies, built-up areas	Low	3
Proximity to stream lines	0–200 m	High	1
	200–400 m	Medium	2
	> 400 m	Low	3
Distance from built-up areas	> 400 m	High	1
	200–400 m	Medium	2
	0–200 m	Low	3
Distance from roads	> 400 m	High	1
	200–400 m	Medium	2
	0–200m	Low	3

COSTDISTANCE was implemented on the eight cost grids for eastern and western source grids, generating a total of *8 pairs* of grids representing accumulative cost distance (Figure 5).

Generation of alternate corridor grids

The CORRIDOR function requires two cost accumulative distance grids created by the COSTDISTANCE function—one grid for each core (or set of cores; Figure 5). Thus, it calculates a cost accumulative distance grid between two cores. Each pair of the eight pairs of cost accumulative grids were set as input grids for CORRIDOR function. The output grids do not identify a single least-cost path (a single line)

Table 2: Cost grid calculation—Step 2+3: difference enhancement by raising cell value to second order and multiplication by cell size (10).

Cost grid Type	*Mark*	*Layer**	*Cost grid calculation* (X* is the cell value of each layer)
(based on a) Single layer	R1	Land cover/use	$10 \cdot X_{lu}^2$
	R2	Proximity to stream lines	$10 \cdot X_{sl}^2$
	R3	Distance from road lines	$10 \cdot X_{rl}^2$
	R4	Distance from built-up areas	$10 \cdot X_{bu}^2$
(based on a) Composite of layers	R5	All layers without weighing	$10 \cdot \sum_{i=1}^{4} X_i^2$
	R6	All layers with triple weigh given to proximity to stream line	$10 \cdot \left(X_{sl}^2 + 3 \cdot X_{lu}^2 + 3 \cdot X_{bu}^2 + 3 \cdot X_{rl}^2 \right)$
	R7	All layers with triple weigh given to distance from road lines	$10 \cdot \left(X_{rl}^2 + 3 \cdot X_{lu}^2 + 3 \cdot X_{sl}^2 + 3 \cdot X_{bu}^2 \right)$
	R8	All layers with triple weigh given to distance from built-up areas	$10 \cdot \left(X_{bu}^2 + 3 \cdot X_{lu}^2 + 3 \cdot X_{sl}^2 + 3 \cdot X_{rl}^2 \right)$

* Since each layer is divided into 3 environmental levels in step 1, cell value, X, ranges between 1–3.

between the two cores, but rather identify the range of accumulative costs between the cores. This can be used to identify the least-cost path from one core to another. For each CORRIDOR grid, a maximum accumulated cost was set visually. An output grid corresponding to a corridor of cells not exceeding the maximum specified cost was generated with the SETNULL function. The resultant threshold output presents graded least-cost corridors. Eight versions of a set of corridors corresponding to the eight abovementioned cost grids (R1–R8) were generated.

Eight corridor maps were generated for all corridor grid types by ArcGIS software to enable spatial analysis and corridor evaluation. The map of corridors that were generated based on the cost grid representing a composite of all four layers without weighing (R5) is presented in Figure 6. Low values (in green colors) represent corridors with a high connectivity level, while higher values (yellow and brownish colors) represent corridors with medium and low connectivity levels.

EVALUATION OF ALTERNATE CORRIDORS

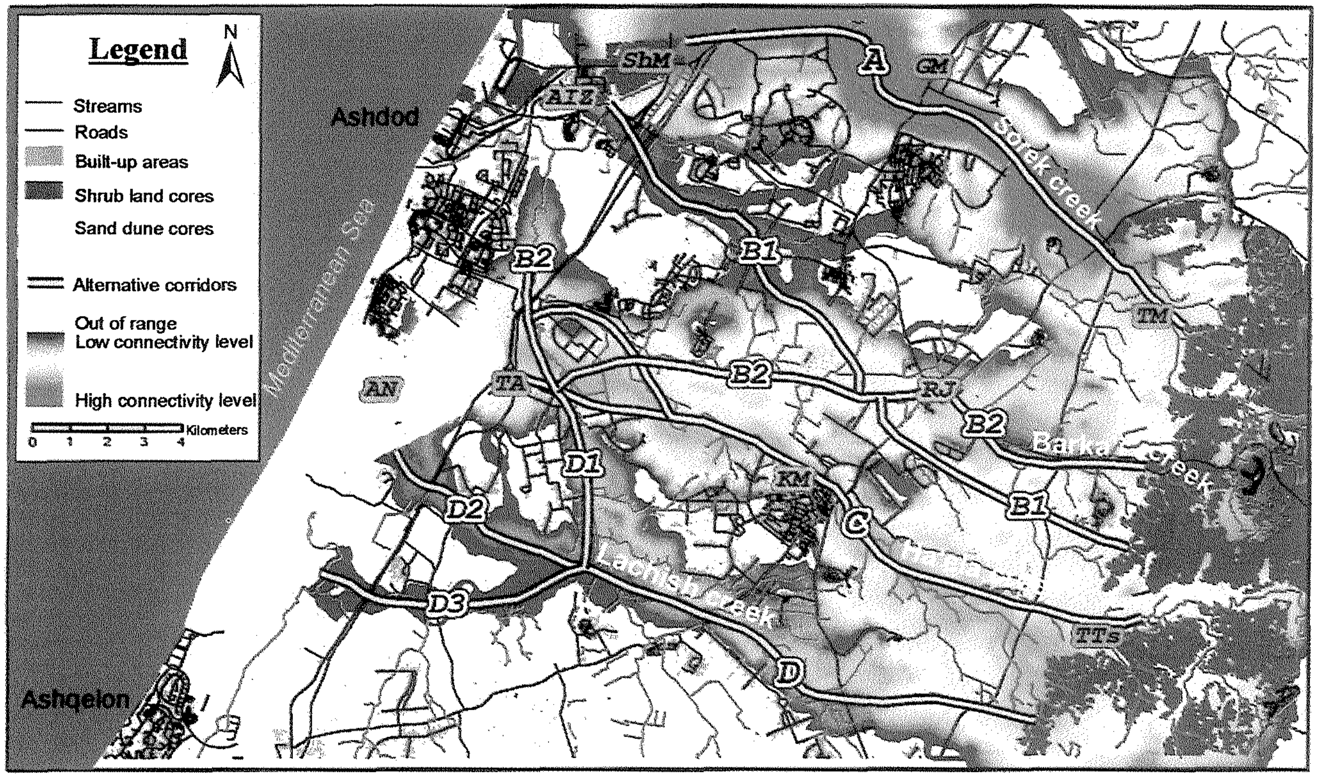
Application of the corridor search function produced a wide range of alternate corridors. By visual analysis of all eight corridor grids, seven best alternatives could be drawn. In general, each is based on one of the four main creeks in this region: Sorek, Barka'i, Ha'elah and Lachish (Figure 6). Figure 6 provides a graphic representation of the alternative potential corridors marked: A, B1–2, C, D1–3. Several spatial configurations can be identified for each of these alternatives, especially at the eastern side of the study area, as the drainage system there is relatively widespread. In addition to the study of ecological networks, such results may assist in planning recreation sites and in creating buffer areas between the different villages and urban areas.

Evaluation of the seven alternatives was achieved by normalized ranking and qualitative progressive analysis. The normalized ranking values were calculated for each alternative (Ai) for each corridor grid (Rj):

$$\text{Norm\_Val}(Ai,Rj) = [\text{Val}(Ai,Rj) - \text{Min\_val}(Rj)] / \text{Std}(Rj)$$

Table 3 presents the normalized ranking values of all combinations. With the exception of the corridor grid, which is based on distance from roads (R3 in Table 3), most values of all alternatives (75 percent) do not exceed 0.5 Std.[1] In other words they are of *very low* ranking values in relation to the overall grid value range and variance level. (The variance level of each corridor grid—R1–R8—is represented by the number of Stds in Table 3). According to these figures, we can say that all seven alternatives represent high connectivity level corridors. These relatively high-leveled corridors show that the area has a significant potential for successful regional landscape planning and design with environmental considerations.

Figure 6: Corridors alternatives routes: *A, B1, B2, C, D1, D2, D3.*



AN=Ashdod-Nizanim Sand Dunes Reserve; *TTs*= Tel Tsafit; *TM* =Tel-Mikne; *TA*= Tel Ashdod; *GM*=Giv'ot Merar National Park; *ShM* =Shita Malbina reserve; *AIZ*= Ashdod industrial zone; *RJ*=Re'em Junction; *KM*=Kiryat Mala'achi

Table 3: Normalized ranking values of alternate corridor routes according to various corridor grids).

Corridor mark	*Various corridor grids based on the various cost grids**								Overall grading
	R1	R2	R3	R4	R5	R6	R7	R8	
A	0.00	0.59	0.00	0.15	0.00	0.01	0.00	0.00	*1*
B1	0.32	0.78	3.11	0.01	0.48	0.32	0.31	0.44	*5*
B2	0.30	0.13	3.01	0.09	0.40	0.36	0.19	0.27	*3*
C	0.28	0.22	2.34	0.30	0.16	0.14	0.07	0.18	*2*
D1	0.53	0.38	2.65	0.17	0.42	0.32	0.21	0.32	*4*
D2	0.61	1.44	1.52	0.30	0.47	0.22	0.39	0.47	*7*
D3	0.55	0.56	2.44	0.47	0.53	0.37	0.41	0.40	*6*
No. of STDs	5.55	6.91	7.89	5.41	4.77	4.73	4.58	5.14	

*R1–R8: see Table 2; low values represent high connectivity level and visa versa; gray cells are normalized values less than 0.5.

The high values of the corridor grid, which is based on distance from roads (R3 in Table 3), imply that in this region, transportation infrastructure represents the strongest ecological disturbance in the context of corridor establishment. Without a well-planned land-use policy, the current accelerated transportation infrastructure development taking place in Israel, might have a destructive effect on the national array of ecological systems.

For comparison between the alternatives, the normalized values were divided into four levels:

- High (H) = 0–0.25 Std;
- Medium (M) = 0.25–0.5 Std;
- Low (L) = 0.5–0.75 Std; and
- Out of range (O) = > 0.75 Std.

Table 4 summarizes the normalized ranking of the seven main alternate corridors according to this division. From the normalized ranking it is clear that Sorek and Ha'elah creeks (marked A and C in Figure 6 respectively) form the principle corridors connecting the shrublands in the east with the sand dunes in the west. The southern alternative of Lachish creek with its three main configurations (marked D1, D2 and D3 in Figure 6) received a relatively low ranking. However, evaluation of all seven alternatives must also consider information that was not utilized in the corridor search. Such information includes bottlenecks, types of connections between the

Table 4: Generalized ranking of alternate corridors and discussion.

Corridor mark	*Main Feature*	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*R8*	*Assessment*
A	Follows Sorek Creek and connects to Yavneh Sand Dunes Area north of Ashdod	H	L	H	H	H	H	H	H	Advantages (Ads.): Wide corridor; shortest corridor; connects to Tel-Mikne (*TM*), Giv'ot Merar National Park (*GM*) and Shita Malbina Reserve (*ShM*); has high ranking in most criteria. Disadvantages (Dis): Connects the a core area north to Ashdod, which is heavily influenced by the industrial zone of Ashdod (*AIZ*).
B1	In its eastern part, follows Barka'i Creek and connects to Yavneh Sand Dunes	M	O	O	H	M	M	M	M	Ads.: Relatively short distance. Dis.: Low connectivity level; relatively narrow; lacks continuity along streams; has a "bottleneck" between Yinon and Kfar ha'Rif; connects to the core area north of Ashdod, which is heavily influenced by the industrial zone of Ashdod (*AIZ*).
B2	Follows Barka'i Creek and connects to Nizanim Sand Reserve at its northern corner	M	H	O	H	M	M	H	M	Ads.: Relatively short distance; connects the Shrublands in the east and Ashdod-Nizanim sand dunes reserve (*AN*). Dis.: Low connectivity level; relatively narrow; goes through a complex roads junction (Re'em Junction; *RJ*); its connection to Ashdod-Nizanim Sand Dunes Reserve (*AN*) is complex.
C	Follows Ha'elah Creek to Lachish Creek and connects to Nizanim Sand Reserve at it northern corner	M	H	O	M	H	H	H	H	Ads.: Shortest distance connecting the Shrublands in the east and Ashdod-Nizanim Sand Dunes Reserve (*AN*); archeological and historic value as it connects Tel Tsafit (*TTs*) to Tel Ashdod (*TA*). Dis.: Has a "bottleneck" between Kiryat Mala'achi (*KM*) and Moshav Kfar Ahim; potentially disturbed from the urban zone of Kiryat Mal'achi (*KM*); its connection to Ashdod-Nizanim Sand Dunes Reserve is complex.
D1	Follows Lachish Creek and connects to Nizanim Sand Reserve at it northern corner	L	M	O	H	M	M	H	M	Ads.: Wide corridor. Dis.: Low connectivity level; lacks continuity along streams; its connection to Ashdod-Nizanim Sand Dunes Reserve (*AN*) is complex.
D2	Follows Lachish Creek and connects to the Central part of Nizanim Sand Reserve	L	O	O	M	M	H	M	M	Ads.: Wide corridor, archeological and historic value as it connects Tel Tsafit (*TTs*) to Tel Ashdod (*TA*); its connection to the southern part of Ashdod-Nizanim Sand Dunes Reserve (*AN*) is wide. Dis.: Low connectivity level; lacks continuity along streams
D3	Follows Lachish Creek and connects to the Southern part of Nizanim Sand Reserve	L	L	O	M	L	M	M	M	Advantage: Wide corridor; its connection to the southern part of Ashdod-Nizanim Sand Dunes Reserve (*AN*) is wide. Dis.: Low connectivity level; lacks continuity along streams.

(R1–R8: corridor grids see Tables 2&3; all site location shortcuts like (*AN*) are presented in Figure 6) corridor and the core areas, corridor width, potential disturbance, and archeological and historic values. Additionally, there are two sites in the study area that have significant values in relation to the evaluation of alternate corridors:

a. Ashdod-Nizanim Sand Dunes Reserve (marked '*AN*' in Figure 6) is the biggest open area in Israel, which embodies natural, landscape, and heritage values unique to aeolian coastal systems (Farajune, 2001).

b. The archeological site of Tel-Tsafit (marked '*TTs*' in Figure 6) attracted special attention as it is related to one of the five ancient Philistine cities—Gat—and it was found to be one of the biggest ancient sites in Israel (Meir, 2001).

Table 4 discusses these types of information related to each alternative under the 'Assessment' column. Some of these data could be implemented within the GIS analysis. However, it would have required a comprehensive session of data acquisition, rather than being used in a comparative way. Furthermore, integrating it within the GIS analysis would increase the dimensionality of the process and could decrease the interpretability of the results. Figure 6 provides visual image coherent with the following discussion.

The corridor that follows Sorek creek (A^2) gained high connectivity levels based on 7 corridor grids (Table 4). Additionally it is the widest and shortest corridor and it connects a national park (*GM*), a natural reserve (*ShM*), and an archeological site (*TM*; Table 4). From these reasons it has been identified as the optimal alternative. Yet, the Ashdod industrial zone (*AIZ*) is adjacent to the western edge of the corridor. This is a major disturbance and pollution source in this area. In addition, it does not connect neither Ashdod-Nizanim sand dunes reserve (*AN*) nor Tel-Tsafit (*TTs*) archeological site.

Therefore, an alternative between corridors B, C and D should also be considered. Both alternatives B1 and B2 have negative accumulative impact on corridor quality. Both are narrow and has relatively low connectivity level (Table 4). In addition, B1 lacks continuity along streams, has a 'bottleneck', and connects to the core area north to Ashdod, which is heavily influenced by the industrial zone of Ashdod (*AIZ*). B2, although it follows Barka'i Creek, goes through a complex roads junction (*RJ*) and its connection to Ashdod-Nizanim sand dunes reserve (*AN*) is complex.

Corridor C is a relatively short route connecting the shrublands in the east and the Ashdod-Nizanim sand dunes reserve (*AN*). It connects Tel-Tsafit (*TTs*) to Tel Ashdod (*TA*). It is also more or less the historical path of Aron-ha'Berit following its capture by the Philistines as told in the Book of Samuel 1 (chapter 5–6). However, corridor C also has two severe limitations: high potential disturbance from the urban zone of Kiryat Mal'achi (*KM*) and the narrow passage formed between Kiryat Mal'achi and Moshav Kfar Ahim.

Corridor D (with its 3 configurations) is relatively wide when assessed with reference to the distance from roads/built up areas. The probable reason for its low ranking even within the land-use/built-up area cost grids seems to be its length. Another disadvantage of corridor D stems from the fact that it does not continuously follow stream channels. If natural vegetation was allowed to fully recover along this corridor, and it could function as a migration route for different organisms, this corridor could become the first choice.

Considering the framework of ecological network concepts and practical implementations, corridors A and Ds exceed the required width of 340 m, since their minimal widths are 800 m and 1000 m, respectively. On the other hand, corridors Bs and C suffer from bottlenecks.

Visual assessment of Figure 6 indicates a clear pattern of concentric rings forming the following hierarchical land-use structure, where:

- Ashdod is the off-center urban locus of the region;
- A central rural ring composed of a relatively dense pattern of villages;
- An agricultural ring with a pattern of low-density villages and mainly field crops surround the central rural zone. This zone includes the northern corridor of Sorek creek and the southern corridor of Lachish creek;
- An outer zone of shrublands and pine forests exists in the east of the study area.

Landscape conservation policies should be implemented in the area, with maximal natural vegetation recovery in the outer rings, which include corridors A and D, and less restrictive development in the dense areas in the center.

SUMMARY AND CONCLUSIONS

A new GIS procedure to delineate corridors based on land-use/cover data and not on species is presented. Seven main corridor routes were delineated on the basis of different environmental considerations for an area covering approximately 600 km^2 located at the southern margins of the central metropolis of Israel. A generalized GIS-based method was utilized. Most corridor zones are based on the main stream channels, pass between built-up areas and are dominated by cultivated lands. These results were not validated in the field, although there is some evidence that these routes are used as travel routes by various species.

Since the balance between the quality of life and environmental values is of national priority and is crucial for future generations, we suggest that:

a. No residence and infrastructure facilities should be expanded at the expense of the delineated corridors, with focus given to corridors A and D.

b. JNF–KKL (Jewish National Fund) will purchase abandoned agricultural areas and those with abandonment potential located along these corridors and will work towards the restoration of natural habitat conditions in these areas.

The least-cost path was found to be of computational efficiency and enables easy interpretation. This analysis can be expanded by adding different criteria, such as environmental sensitivity level, pollution levels and densities of built-up area and infrastructure. Information on parcel ownership may also be of great importance for decision making process. However, even though it is generalized, the method presented has led to significant and implementable alternatives of corridors. The GIS approach enabled the delineation of green corridors on a relatively large scale with precise contour lines. The simplicity of this process is an advantage, since it can be readily applied to the entire country using standard data sources such as those used here. These contour lines can be used by the authorities to address practical land management designations and landscape planning.

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NOTES

1. Std. = Standard Deviation is one indicator for a variance level of a set of figures.
2. All site location shortcuts like *(AN)* in this paragraph are presented in Figure 6.

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