Assessing connectivity between open spaces using GIS

Information from SEFGIS

The use of Geographical Information Systems (GIS) in landscape connectivity is currently limited. From an ecological point of view, connectivity refers to the movement or migration of species between habitats and is considered essential for species survival, diversity, migration, gene flow and decolonisation. A challenge faced by the Geo-Information Sciences is the application of connectivity analysis to environmental data through the use of a vector model, with habitats as the unit of measurement. This article focuses on a new approach to using GIS as a tool in assessing landscape connectivity.

The Sedibeng District Municipality (SDM) appointed Strategic Environmental Focus (SEF) to undertake the Sedibeng District Open Space System (S'DOSS) project. SEFGIS, closely aligned with SEF, was assigned the GIS-related work for S'DOSS. The intention of the S'DOSS is to link open spaces into a connected, interdependent network that will contribute to the sustainability of the district, providing important linkage opportunities for species and enhancing ecosystem function.

The SDM, which is located on the southern border of Gauteng, includes the Emfuleni, Lesedi and Midvaal Local Municipalities and is 420 124,58 ha in size. The District is facing immense development pressure and must consider the creation and management of a sustainable ecological network, for various reasons. The key objective of conservation in Sedibeng is the preservation of the Highveld Grassland Biome and specific endangered species of invertebrates, including the rare Heidelberg Copper Butterfly - The Red Data Plant policy (GDACE, 2001a), Ridges policy (GDACE, 2001b) and Conservation Plan (GDACE, 2003) of the Gauteng Department of Agriculture, Conservation and Environment (GDACE) highlight the importance of additional protection and management of sensitive species, as well as the importance of the quartzite ridges of Gauteng in the conservation of biodiversity.

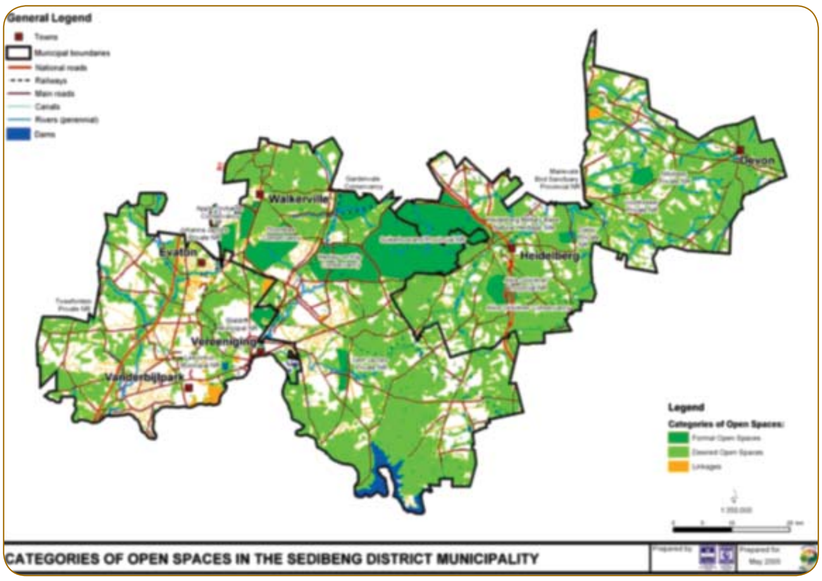

Fig. 1: Categories of open spaces in the Sedibeng District Municipality.

Currently, 9% (38 176 ha) of the SDM is formally protected, with 20 732 ha conserved as provincial or municipal nature reserves. These are isolated patches of conserved land, which do not necessarily promote species migration. In order to create a consistent open space management system across the SDM, the S'DOSS project was launched which would allow for the management of open spaces in line with international, national and provincial policies. SEFGIS assisted SEF in reaching this goal by assessing inter alia the connectivity of open spaces in the SDM using a GIS.

Open spaces - definitions and catagories

For the purposes of the S'DOSS, an "open space" was defined as "any land that is vegetated and is under no or low-intensity development". An open space system is an "inter-connected and managed network of open space, which supports interactions between social, economic and ecological activities, sustaining and enhancing both ecological processes and human settlements. It comprises public and private, man-made or delineated spaces and undeveloped spaces, disturbed natural spaces and undisturbed/ pristine natural spaces.

Open spaces were classified into three categories for the purpose of this project, namely formal open spaces, desired open spaces and linkages (see Fig. 1). Formal open spaces includes nature reserves, conservancies and any other open space formally set aside for the purposes of protecting ecological diversity or function. Formal open spaces are not readily available for development. This category also includes the protected areas identified within C-Plan (GDACE, 2003).

Desired open space is any land, which is not a formal open space and has been deemed important in terms of the S'DOSS due to its function as an ecological corridor or its ecological sensitivity. Certain vegetation categories, as captured for the Sedibeng District's State of the Environment Report, were used as a base for the desired open spaces. These include the grasslands, koppies and outcrops, indigenous woodlands, ridges and wetlands.

Linkages are those areas that do not fall within formal or desired open space, but which enhance the connectivity and/or ecological function of formal or desired open spaces. These open spaces cannot be set-aside as formal open spaces due to their existing or potential land uses. For the purpose of this project, linkages include airfields, defence land, heritage sites, power lines, recreational areas and parks, cemeteries as well as institutional facilities. These open space categories were the basis on which a possible ecological network could be established.

Connectivity and topology

The term connectivity is used in a variety of disciplines to describe an interrelationship between elements or features. Simply put: "Topology is the mathematical method used to define spatial relationships … . " (Aranoff, 1989:174). The term spread its meaning to many other disciplines, including ecology and geography.

From an ecological perspective, connectivity assessments deal with the relationship between species and their habitats over time. On the one hand, it refers to the migration of species between seasons and over large distances (migratory connectivity) while on the other hand it refers to the migration of species between habitats within short distances and within a season (landscape connectivity). SEF primarily focused on the landscape connectivity definition that will enable the other two types of ecological connectivity.

The S'DOSS must function to reduce the negative impacts of landscape fragmentation by enhancing overall connectivity. Essentially, "connectivity implies the movement of entities over time and space … ." (Abler et. al., 1972:236). Although topological studies were carried out in 1736 by Euler, in 1945 Robert Horton first applied the concept geographically to river patterns. To date, spatial connectivity is widely studied in numerous applications, such as transport, communication networks, service infrastructure, retail, ecology, river systems, agriculture, climatology, pollution and geomorphology. Geographers took interest in many of the above-mentioned applications in order to analyse the spatial aspects of connectivity.

Spatial connectivity analysis methods

Abler et. al. (1972) explain that there are sixteen different classes of movement and spatial interaction (i.e. connectivity) possible between points, lines, areas and volumes. Connectivity is, however, mostly applied to networks, consisting primarily of points and lines as the building blocks. Networks simplify the representation of movement in space to a measurable level and can accommodate parameters of cost, distance, direction and barriers.

Quantitative measurement of connectivity involves matrices that reflect the linear relationship between variables and the degree of connectivity between them. Various indices were developed by Kansky (1963) who distinguished between topological parameters that aim to describe the whole network, versus those that focus on specific elements within the network. The cycle number, alpha, beta, gamma, eta, pi, Iota and theta indices were used to describe the entire network, whereas connectivity (beta-index), accessibility (shimbel-index), centrality (könignumbers) and directness (Detour index) were used to describe the specific elements within a network. In a study in New Mexico (University of New Mexico, 2004), three methods for measuring landscape connectivity were identified: the alpha index, the gamma index and the connectivity matrix. In order to assess landscape connectivity, data should be represented as a topological network model. Millán de la Peña et. al., (2003) assessed connectivity by calculating the number of connections of hedgerows as habitat for invertebrates per hectare, which could easily be presented as lines and nodes. As GIS tools, connectivity functions are grouped into "contiguity, proximity, network, spread, stream, and intervisibility … ." functions. The connectivity functions in GIS are applied to both raster and vector models and is quantitative or qualitative in nature (e.g. intervisibility analysis). Various studies used GIS cost-distance or least-cost path modelling to identify possible corridors between habitats. Least-cost path functions allow for friction in the landscape through the use of weighted distances and barriers, and are based on habitats and the functional distance between them.

This methodology was considered for the analysis of connectivity for S'DOSS, but was not utilised owing to the need for cumbersome conversion of data sets; computations to assign weights and the iteration of the process to obtain multiple corridors. After consideration of limitations of existing methodologies, a novel approach was utilised to apply landscape connectivity analysis within a polygons vector model in GIS.

Methodology

It is important to reflect open spaces as areas with a particular extent (polygons) in the S'DOSS project. This enables the calculation of surface area of potential habitats and its ratio to the rest of the SDM. Open spaces can be related to zoning and ownership through cadastral data that is topologically correct (some parcel overlap may occur in cadastres) and will enable common boundaries and corners, which imbeds topology into the model. The extent of wetlands within the 1:50 year flood line were delineated in compliance with the National Water Act (South Africa, 1998). This offered better land use planning and decision making in that areas where it is a risk to develop are flagged and are declared more suitable for ecological land use. In this way, sensitive environmental features were captured within the S'DOSS in order to inform decision making and sustainable development.

Open spaces were captured in ArcGIS 8.3 as polygons with boundaries representing the extent of the categorised open spaces. Formal open spaces were considered to form the skeleton of the open space system in Sedibeng, because they have been formally set aside for the purposes of conservation and protection of key habitats and are not under direct development pressure.

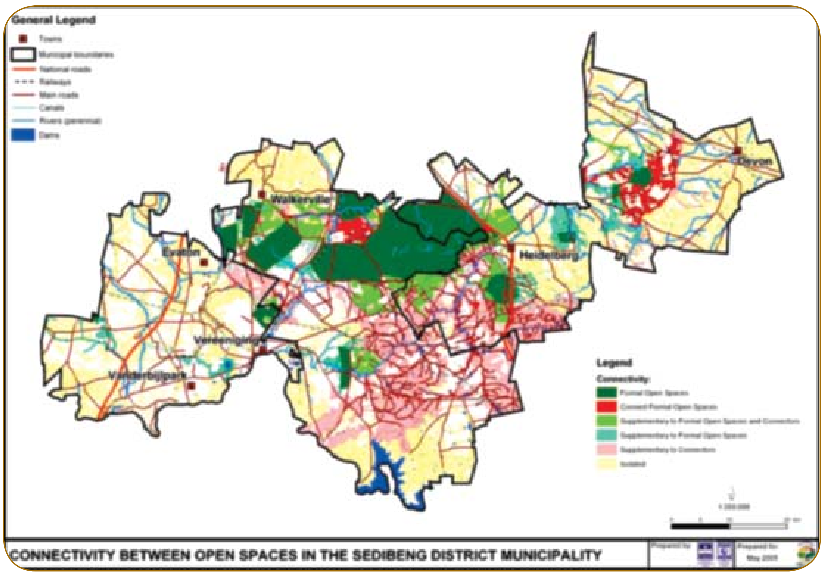

Fig.2: Connectivity between open spaces in the Sedibeng District Municipality

A functional open space system will build on the formal open spaces and enhance their ecological function through improving connectivity. Desired open spaces, on the other hand, do not enjoy formal conservation status, and it is in the interest of the SDM to protect those spaces that are environmentally important. Desired open spaces were ranked in terms of their environmental importance within the SDM. The classification of the desired open spaces in terms of their connectivity in relation to formal open spaces would assist in targeting areas to be preserved for species migration and enhancing connectivity. Rivers (a type of desired open space) naturally function as important open space connectors as in other applications (USDA, 2004). The Rietspruit, the Kliprivier and the Suikerbosrand River, tributaries of the Vaal River, allow for creation of a continuous system of open space. Areas adjacent to rivers that connect two or more formal open spaces, can enhance the surface area and functionality of the river connector. These areas were considered critical in the assessment of connectivity of desired open spaces.

Using ArcMap as a platform, desired open spaces were assessed in terms of the role they fulfil as connectors of formal open spaces. Desired open spaces were selected in terms of their proximity to formal open spaces. Desired open spaces that were adjacent to two or more formal open spaces, were classified as "connectors". Desired open spaces in close proximity to formal open spaces or connectors were classified as "supplementary", whereas the remainder of desired open spaces were classified as "isolated". Fig.2 illustrates the results of the analysis.

Discussion of the results

Wetlands naturally form the most important connectors in the SDM. Linear wetlands cover a large extent of the SDM and generally connect more than one formal open space, enhancing connectivity. Proximity of formal open spaces plays a significant role in landscape connectivity analysis. Some features such as roads, railways, and fences, can act as permeable or absolute barriers to species movement. "... (A) region may be connected for birds, but fragmented for snails ... ." (Green & Sadedin, 2005:4). Open spaces, which were identified as possible connectors, should be further investigated to determine the existence and nature of the barriers and where necessary, methods of enabling particular fauna to migrate between the identified areas should be implemented.

GIS formed a reliable and successful tool in the representation of the categories of open space, as well as in determining interrelatedness of open spaces in order to prioritise areas for conservation. The area vector model approach enabled precise positioning and surface area calculation. Where possible, the established formal and linkage open spaces were captured to cadastral boundaries, before integration into one file of open space categories. This enables relationships to other cadastral-related data, such as zoning and ownership, which assist integrated decision making. Furthermore, ecological sensitivity ratings, habitat type, habitat quality, level of disturbance and presence of faunal species, as well as other information can be linked through relational databases to these open spaces.

The extent of the district made processing a relatively quick process and no need for rasterisation or compression arised. Topology is built into the data structure through adjacent open spaces sharing vertices and arcs, which enabled the use of proximity analysis to determine the connectivity in the landscape. Topological data ensures more rapid processing because the coordinates of each point are not processed.

Change in land use is inevitable, and the S'DOSS will require updating. Updating is usually difficult in that remote sensed data is not easily available. Data sets also quickly become outdated as new policies are implemented. Digitising is a tedious process and it is important for the GIS operator to recognise different types of natural vegetation categories and gain competency in digitising in order to obtain a high level of spatial accuracy.

Simplification of areas to a proper network model would enable quantitative analysis. Reducing the areas to polygon-centroids that connect through straight lines will, however, give an oversimplified view of the possibilities of landscape connectivity between areas. It will be beneficial to extend the area model to include barrier types as well as to allow for automated procedures through programming successive commands.

Conclusion

A new approach to landscape connectivity analysis was investigated with the use of GIS as an analysis tool. Desired open space categories were analysed and ranked in ArcGIS 8.3 based on their proximity to established formal protected areas. The connectivity analysis is considered useful in decision making regarding open space management.

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