69

GIS and landscape conservation

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This chapter reviews recent and current use of GIS for landscape conservation, and uses these applications to identify the kinds of developments needed in order to expand the utility of GIS for these applications in future. Landscape conservation is considered in the broad context of integrated ecological systems that include both physical and human components. This interpretation is developed from both geographical and ecological perspectives in order to identify the role of geographical information and GIS. The geographical perspective draws on the historical tradition of geography as an integrative science in which landscape is a central feature for study and spatial and ecological analyses have fundamental roles; the interaction of social and physical systems is at the core of this integrative approach. The ecological perspective focuses on environmental topics associated with conservation of wildlife and biodiversity, planning and management of nature reserves, interpretation and protection of scenery, and management of relationships between different land uses. An important component is that human activity is implicit rather than 'nature' being considered independently of human action. The traditional approach to landscape conservation has been through establishment of designated sites that are considered independently of their surroundings and within which conservation is treated as the major, or only, land use. More recently the wider geographical context of designated sites has begun to be considered and approaches based on cooperation have replaced competition between land uses. This has been given immediate relevance by initiatives related to sustainable development. Biodiversity is a basic component of sustainability and serves to foster linkage between landscape conservation and other land uses. Sustainability also emphasises the interdependence of human populations and environmental resources. Examples of wide area conservation evaluation that deal with these issues are emerging and are important indicators of future trends and topics for application of GIS in landscape conservation.

1 INTRODUCTION

Landscape conservation in its widest sense encompasses the planning and management of wildlife and scenic resources in geographical and ecological systems. These systems include both physical and human components.

This working definition is deliberately broad in order to include a wide range of current and potential applications of GIS. It also allows principles to be developed that guide extension of GIS-based approaches. The definition does not assume a particular form of resources (e.g. land, air, or water), but rather is concerned with the interaction of environmental and human systems and with general principles relevant to conservation of any resource base.

There are four key elements of this definition:

1 human activity and socioeconomic systems are explicitly involved (Hansen et al 1993; Hobbs et al 1993);

2. it includes a variety of demands placed on a finite resource base;
3. it overlaps with a range of environmental and socioeconomic sciences including biology, ecology, economics, environmental science, landscape ecology, planning, and geography (Brussard 1991);
4. it focuses on a systems approach that is the basis for synthesis and integration of methodologies and perspectives on issues.

1.1 Principles for GIS in landscape conservation

Rather than catalogue the many examples of GIS applications in landscape conservation, the approach in this chapter is to identify and illustrate more general principles that serve as a framework within which landscape conservation applications of GIS can be assessed and developed in future. These principles are mostly drawn from geographical and ecological sciences and focus on three themes:

1. biodiversity and sustainability as concepts that have been adopted to guide and focus conservation efforts and land (use) management generally (Grehan 1993);
2. the tradition of geography as an integrative science that emphasises spatial concepts and uses 'landscape' as an object for analysis (Couclelis, Chapter 2; Johnston, Chapter 3; Hartshorne 1939; Holt-Jensen 1980; Unwin 1992);
3. the contribution of ecological understanding to planning and managing specific resources in particular locations and real-world contexts.

These three, individually and collectively, also emphasise the interdependence of human and environmental systems.

2 BIODIVERSITY AND SUSTAINABILITY

Bridgewater (1993) describes two objectives for nature conservation: maintaining the maximum degree of biodiversity; and developing, managing, and maintaining the ecological infrastructure through the designation and management of protected areas. Biodiversity has largely replaced species and habitats as the primary focus of nature conservation efforts and is a complex and inclusive concept (Swanson 1992). For example, biodiversity operates at different levels of taxonomic organisation from genetic to ecosystem and at spatial scales from global to local (Gaston 1991). The need for spatial and taxonomic data to support Biodiversity Action Plans provides GIS with an important role in developing, managing, maintaining, and analysing (Collar 1996) the information base that supports strategic and local planning related to biodiversity (Ahearn et al 1990; Gaston 1994; Harrison 1995; Margules 1989; UNEP 1994). Integration of biological records, inventory of resources (Sætersdal and Birks 1993; Stoms and Estes 1993), and evaluation of geographical patterns of diversity (McKendry and Machlis 1991; Norton and Nix 1991; Scott et al 1993; Walker and Faith 1993) at different geographical scales (Thomas and Abery 1995; Vail 1993) are all aspects to which GIS can be applied.

The concept of biodiversity is not limited to nature conservation and biological organisation, however (Burton et al 1992; Kangas and Kuusipalo 1993), since it is a core component of sustainable development as debated following the Bruntland Report (WCED 1987) and the Convention on Biological Diversity (UNEP 1992). Within this wider context of sustainable development, other attributes of landscape and human use of environment become part of biodiversity. This need to link conservation and development (Adams and Thomas 1996; Mwalyosi 1991) and human activity with environmental quality for planning and management presents the GIS community with an important challenge: to develop GIS that can fully explore the concept and practice of sustainability in ecological systems. Until recently, approaches to landscape conservation have been relatively narrow and focused on single issues such as species or habitat conservation through the mechanism of site designation on the basis of special characteristics. Designations relate to one or more of several criteria (such as those listed in Table 1) that are applied locally (e.g. Local Nature Reserves), nationally (e.g. National Nature Reserves), internationally (e.g. RAMSAR or NATURA 2000 sites in Europe), or globally (e.g. World Heritage Sites). Increasingly, GIS are being used to manage data for these sites, analyse and evaluate their characteristics, develop management plans (Alexander 1995), and examine their significance in relation to the wider geographical context of site protection (McKenzie et al 1989; Petch and Kolejka 1993). This approach treats conservation as a land use with zoning designed to keep competing uses separate. Although necessary

Table 1 Criteria for nature reserve selection (from Ratcliffe 1977).

Size (extent)
Position in an ecological/geographical unit
Diversity
Rarity
Typicality (representativeness)
Fragility
Naturalness
Recorded history
Potential value
Intrinsic appeal

and practical in some circumstances, it is of limited potential for reconciling and managing growing pressures on land resources, particularly as world population increases (McMichael 1993). More recently, therefore, the wider geographical context of (designated) sites, the growing relevance of resource management for multiple uses, the inclusive nature of biodiversity, and the interdependence of physical and human systems are being considered. This will lead to more holistic approaches to resource use based on cooperation with multiple use replacing competition between uses.

3 GENERAL PRINCIPLES

Although debated widely (Johnston, Chapter 3; Forer and Unwin, Chapter 54; Unwin 1992), the tradition of geography is of an integrative science that deals with human and environmental phenomena of the Earth. This tradition provides three features of special relevance.

3.1 Landscape is a central object for study

The definition of landscape conservation in section 1 above has much in common with the varied definitions of 'landscape' developed within geography since 1900 (Holt-Jensen 1980). The German concept of *Landschaft*, broadly analogous to landscape, also means a scientifically-defined geographical region and is a concept that spans systematic and regional approaches to geographical enquiry (Holt-Jensen 1980). This remains a necessary role with the advent and application of GIS since the data management and analytical mechanisms provided through GIS software provide an environment within which the regional (data description) and systematic (thematic processes) may be linked. Landscape has been subdivided into five main classes (Fochler-Hauke 1959):

1. landscape morphology, considering the form and spatial structure of phenomena;
2. landscape ecology, concerned with functional interrelationships;
3. landscape chronology, concerned with development of regions over time;
4. regionalisation;
5. landscape classification.

These present different approaches to definition and study of regions and have relevance to the development of GIS for landscape conservation applications. Examples of using GIS to develop regional landscape classifications can be found in contemporary landscape conservation (Davis and Dozier 1990; Klijn and Udo de Haes 1994; Soriano and Paruelo 1992). These regionalisations form the basis for conservation planning and assessment but suffer from a number of limitations including:

- use of coarse, or geometrically inappropriate, spatial units with abrupt boundaries;
- having variable quality in the base data possibly leading to misclassification;
- providing a static taxonomy that may not be the most appropriate for the specific issue/application.

As planar-enforced categorical maps these regional landscape classifications also have other limiting attributes described elsewhere (Aspinall and Pearson 1995; Goodchild et al 1992). A GIS that can produce alternative regionalisations and landscape classifications appropriate to particular conservation questions would be a useful management tool within existing structures for decision-making in landscape conservation.

Landscape morphology, concerned with form and spatial structure, and landscape chronology, the development of regions over time, were developed in geography, but have been little used in GIS despite the relevance of pattern and process to many landscape conservation issues. The growth of efforts to link GIS with environmental modelling (Goodchild et al 1993, 1996; Wheeler 1993) and to develop spatial pattern analysis methods and applications in wide area conservation and ecology (Aspinall 1994a; Simpson and Dennis 1996) indicate a role for GIS in landscape conservation through providing rigorous analytical tools to explore pattern and process at landscape scales. At present this mostly takes place within landscape ecology, which has re-emerged as an interdisciplinary subject concerned with the structure and function of ecological communities in spatial landscapes (Forman and Godron 1986; Hansson and Angelstam 1991; Wiens 1992). The focus on spatial structure and real-world environmental variability, as well as a concern for large geographical areas, has meant that landscape ecologists have readily adopted GIS technology. GIS is used to describe and analyse the structure of habitats in landscapes (Baker and Weisberg 1995; Gustafson and Parker 1992; Hansson 1992; Kruess and Tscharntke 1994; Krummel et al 1987; Olsen et al 1993; Pastor and Broschart 1990; Plotnick et al 1993; Taylor et al 1993; Turner 1990; Wickham and Norton 1994), and as an arena for applying models of population dynamics in spatial landscapes (Baker 1992; Schulz and Joyce 1992; Stamps et al 1987; Verboom et al 1991). Techniques for the description and evolution of pattern are also being developed including cellular automata (Wolfram 1984), percolation models (Gustafson and Parker 1992), hierarchical neutral models (O'Neill et al 1992a, 1992b), and others (Turner et al 1989). Application of these to practical conservation is currently a research question for GIS.

3.2 Spatial analysis

Much of the utility of GIS rests in its ability to manage and manipulate spatial data. Spatial reasoning, however, has received only limited attention in ecological applications where development and experimentation has focused on elucidating processes rather than analysis of pattern (see Getis, Chapter 16, and Openshaw and Alvanides, Chapter 18, for general perspectives on the spatial analysis research effort). This reflects interest in 'why' questions and in mechanisms as the causes of observed patterns of distribution and abundance (Andrewartha and Birch 1954; Gotelli and Simberloff 1987) rather than analysis of spatial phenomena represented by the patterns of distribution. Dobson (1992) discusses the concept of spatial logic and its relationship with process studies in palaeogeography, and has used both spatial and process logic to analyse forest blowdown and lake chemistry in the Adirondack Mountains of the USA (Dobson et al 1990). A variety of statistical and spatial analytical methods have been developed and applied to wildlife–habitat relationships, both to interpret environmental associations from patterns of distribution and to model distribution from limited survey and incomplete biological records. Methods include Boolean logic (Eastman, Chapter 35; Jensen et al 1992), habitat suitability models (Breininger et al 1991), weights-of-evidence (Bonham-Carter et al 1988), Bayesian models (Aspinall 1992, 1994a; Milne et al 1989; Pereira and Itami 1991), decision-trees (Grubb and King 1991; Lees and Ritman 1991; Moore et al 1991; Walker 1990; Walker and Moore 1988), monotonic functions (Mackey 1993), artificial intelligence (Fischer, Chapter 19; Openshaw and Alvanides, Chapter 18; Davey and Stockwell 1991; Folse et al 1989; Saarenmaa et al 1988, 1994), and statistical methods such as multivariate models (Getis, Chapter 16; Clark et al 1993; Livingstone et al 1990), canonical correspondence analysis (Hill 1991), generalised linear modelling (Austin et al 1990; Buckland and Elston 1993), and generalised additive modelling. A number of purpose written software packages have also been developed to apply particular forms of modelling and analysis including BIOCLIM (Lindenmayer et al 1991) and HABITAT (Walker and Cocks 1991). These methods have each found application and their use, validation, and application to practical conservation issues is expected to increase since they:

- provide objective means to add value to survey (Nelder et al 1995);
- explore relationships at large geographical scales (Aspinall 1994b; Liebhold et al 1992; Schmiegelow 1990);
- focus attention on the quality and uncertainty of information bases available for use in decision-making (Flather and King 1992; Hess 1994; Hobbs and Hanley 1990; Salski 1992; Stoms et al 1992);
- provide a means for predicting impacts of land use, climatic, or other changes (Agee et al 1989; Baker 1989; Dale and Rauscher 1994).

3.2.1 Spatial dependence

Geostatistical methods have been widely used in landscape conservation (Robertson 1987; Rossi et al 1992; Sokal et al 1987), although most consider distance (e.g. Kriging) rather than spatial variation in a related variable such as habitat (e.g. co-Kriging), and thus do not account for habitat relationships (see Anselin, Chapter 17; Getis, Chapter 16, for general reviews of geostatistical methods, including Kriging). Other spatial analytical methods that describe spatial pattern such as Moran's *I*, Geary's *c,* and the Getis and Ord *G* statistics (Getis, Chapter 16; Getis and Ord 1992) are also beginning to find application in landscape conservation research. For example Qi and Wu (1996) use spatial autocorrelation indices to examine the relationship between pattern and scale at multiple geographical scales. They use Moran's *I*, Geary's *c,* and the Cliff–Ord statistic to analyse digital datasets of topography and biomass in peninsular Malaysia. Addicott et al (1987) discuss concepts associated with environmental patterning, spatial and temporal scales of ecological processes, and response of organisms to environmental pattern. They develop a concept of ecological neighbourhoods to represent these aspects of scale. In a different object-orientated approach to scale, Aspinall (1995) has used Moran's *I* as one of a set of descriptors of scale for geographical data. Specifically, spatial autocorrelation, measured as spatial dependence with Moran's *I*, describes a component of the behaviour of the geographical and thematic information contents of spatial data at a range of sampling intervals. Since Moran's *I* can be applied to values at different geographical distances within a dataset, the relationship between spatial dependence and scale can be examined. This is useful for understanding the interaction of spatial structure and spatial heterogeneity as the variability of data from place to place (Aspinall 1995; Kupfer 1995).

Aspinall (1996) also uses Moran's *I* to describe and analyse spatial structure and habitat function in complex landscapes in which patches are not obvious. The results are informative about spatial structure and, since they incorporate details of scale and scaling, indicate the spatial distances over which 'patches' may exist or operate. The use of Moran's *I* provides a generic method for quantifying landscape into patches with a particular scale even in areas where no obvious patch structure is apparent. Further research is needed in the application of the measures of structure and function provided for landscape ecology (Cullinan and Thomas 1992), but the approach provides a link between description of pattern at multiple geographical scales within a heterogeneous environment and analysis of spatial structure. Since much of landscape ecology is based on analysis of patches and their organisation in the landscape (Fahrig and Paloheimo 1988), objective methods for defining patches such as those provided by spatial dependence statistics can make the landscape description on which landscape ecology depends more rigorous and objective. This will help add to understanding of spatial organisation in landscapes and contribute to development of more realistic landscape ecological models.

3.2.2 Data sources

An issue in this context is the source data for habitat and vegetation mapping, since land cover and habitat data are the common element within almost all landscape conservation and landscape ecological applications (Frank 1988). Maps and remotely-sensed data can be used to derive and record land cover (Barnsley, Chapter 32; Bibby and Shepherd, Chapter 68; Dowman, Chapter 31; Herr and Queen 1993; Hodgson et al 1988; Homer et al 1993; Robertson et al 1990; Wallin et al 1992), although the latter may be preferable (Roughgarden et al 1991). Perhaps most important from the perspective of developing spatial analysis for landscape ecology is the limitation of maps which will usually provide habitat data as discrete, sharply bounded, internally homogeneous polygons (Aspinall and Pearson 1995; Goodchild et al 1992). This cartographic model is limited since it imposes spatial organisation through the mapping process and this is then fixed for subsequent analyses in which it can exert a strong influence (Martin, Chapter 6; Stoms 1992). In contrast, satellite imagery and digital air photography provide a surface of variation and can be used to investigate generalisation and scale effects (Bibby and Shepherd, Chapter 68; Simmons et al 1992); they also provide wide geographical coverage and regular updates are available. This gives remotely-sensed data many advantages over field survey for gathering certain types of land surface data, principally land cover data (Simmons et al 1992). Since a prerequisite for the analysis of spatial dependence using Moran's *I* is a continuous field representation of environmental variation, remote sensing is an important data resource. Franklin

(1995) reviews habitat mapping techniques and data sources for remotely-sensed data.

3.3 Ecological analysis

In contrast to the lack of attention it has paid to spatial logic and analysis, ecological research has supplied many principles of practical use in landscape conservation and is rich in theory and concepts which relate to processes and ecological function (Hoekstra and Flather 1986). For example, ecosystems science includes niche theory, energy flow and trophic structure, and biogeochemical cycling, while population biology includes interspecific and intraspecific interactions, population regulation, and life-history strategies. Reviewing these topics of ecosystems science and population biology, Levin (1992) has argued that the problem of pattern and scale is the central problem in ecology, providing a unifying concept and linking basic to applied ecology. Since landscape conservation is concerned with real-world locations and situations the importance of pattern and scale becomes highlighted and this emphasises the need to couple ecological science with spatial concepts and methods (Hanski 1994; Hanski and Thomas 1994; Ims et al 1993). Landscape ecology provides a conceptual framework for this coupling (Probst and Weinrich 1993; Wiens et al 1993) and GIS provides an obvious mechanism by which it may be achieved (Haines-Young et al 1993; Stow 1993). The interaction of spatial and temporal scales, with each other and with phenomena at different levels of ecological organisation, needs to be developed. This will then provide a framework for the analysis and synthesis of ecological problems, methodologies, and techniques. This in turn will enhance the application of GIS to ecological and landscape conservation problems.

An example of this form of structured approach in which spatial and temporal scales are explicit is provided by Walker and Walker (1991) who use a GIS for the North Slope in Alaska to investigate questions related to energy development and climate change. The GIS is organised with a hierarchical database based on spatial and temporal scaling of data sources and natural disturbance phenomena (Delcourt et al 1983; Delcourt and Delcourt 1988) and is used to analyse a range of phenomena at a variety of scales. Important technical and methodological issues which emerge include the question of scaling and the relationship between data sources, and scale and topic of investigation. Developing this approach is based on initial specification of the problem to be investigated followed by structured design of the GIS to develop databases and analytical processes that help solve the problem. Investigation of appropriate design of GIS for specific landscape conservation applications is not widely carried out, but would be of great benefit.

Addressing issues of data, data quality, analytical processes, and information output will lead to specification of appropriate data models to support analysis and help tailor GIS to user needs. It will also focus research on practical problems of landscape conservation. The close link emerging between landscape ecologists and GIS, and between spatial analysis and landscape ecology (Tilman 1994) has developed from an applications need; further attention to GIS planning and design issues from the GIS community will help develop data models and analytical procedures that are of greater practical use for landscape ecology and landscape conservation applications.

Aspinall (1994b) reviews some of the opportunities for ecological research to benefit from spatial analysis and spatial modelling linked to GIS (for discussions of the general debate about integrating spatial analysis with GIS see Anselin, Chapter 17; Getis, Chapter 16; Openshaw and Alvanides, Chapter 18). The two main classes of development relate to spatial analysis methods and data quality management, as shown in Table 2. Johnson (1990) and Hunsaker et al (1993) review the role of spatial and process models in landscape ecology and these provide a further set of design needs. Examples of ecological process models linked to GIS demonstrate the practical relevance of this linkage (Burke et al 1990; Johnson et al 1992; Johnston and Naiman 1990). The representation of landscape conservation problems remains largely unknown, however, partly because landscape conservation is a broad applications area growing in response to biodiversity issues, and partly because the application of GIS-based analyses and models needs to be tested. Data quality is still an important issue, particularly as outputs from GIS processing are used to support decisions that may affect survival of a threatened species, or the balance between land for conservation and economic development to sustain rural communities (Barrett 1992).

Table 2 Data quality and spatial analysis functions for linking GIS and spatial analysis to ecological modelling (based on Aspinall 1994b).

Class of function	*Purpose*
	Data management
metadata	description of data quality (for analysis of uncertainty)
scale, resolution, grain	identify appropriate scale and problems for application for data
	Analysis/GIS processing
sampling	methods for assessing validity and representativeness of samples drawn from spatial data for different analyses
data generalisation and aggregation (change of data scale)	methods for generalising spatial and object attributes of data
enhancement	methods for generating synthetic data with finer basic spatial units (resolution)
pattern description	methods for describing spatial pattern and spatial interaction in ecological distributions
pattern analysis	methods for analysis of spatial patterns and spatial interaction effects; methods for generating spatial and ecological hypotheses about pattern–process relationships at a given spatial scale – based on spatial and process logic
pattern generation and hypothesis testing	methods for generating spatial patterns from stochastic (pattern-generating) processes for comparison with observed distributions
error analysis	integrated management of error in analysis; models of error propagation to provide confidence limits to accompany output from (GIS) analysis
description and analysis of scale influences	methods that translate between scales (scaling up and down) in data and models
linking process models with GIS	ecological and environmental process models that incorporate location and spatial interaction effects

3.4 Landscape conservation as the interaction of social, economic, and physical systems

With an increasing number of aspects of landscape conservation that require solutions based on integrated approaches (Margerum and Born 1995), particularly as sustainability motivates and guides resource management objectives, the direction for development and application of GIS in landscape conservation is towards the linkage and integration of human and physical environmental systems (Flamm and Turner 1994; Hobbs et al 1993; Kangas and Kuusipalo 1993; Mooney 1991).

A systems approach is one mechanism by which such integration may be achieved (Perrings et al 1992). Haggett (1979) presents a systems approach based on spatial analysis, ecological analysis, and regional complex analysis as the core of geography and Holt-Jensen (1980) and Unwin (1992) have argued that these have importance for developing geography as a basis for synthesis. Clayton and Radcliffe (1996) describe a systems approach to sustainability that offers a basis for liaison between disciplines on philosophical, methodological, and technical levels that will allow their diverse modelling approaches to be coupled with one another and with GIS. In part, the interaction of the different models and the perspectives represented serves to define a multi-disciplinary scientific method. The approach described by Clayton and Radcliffe links hard systems (Hall 1962) and soft systems (Checkland 1981) methodologies, draws on the properties of emergence, hierarchical control, and communication developed from General Systems Theory (Bertalanffy 1969; Simon 1969), develops understanding from the study of complex adaptive systems (Holland 1975), and integrates biophysical and socioeconomic factors within a common framework such as environmental economics. Clayton and Radcliffe also identify a specific role for GIS in the management and integration of disaggregated data; this allows GIS to bring model outputs and other data together in a flexible way to evaluate alternative options within decision-making processes; Rhind (1991) has also identified this role for GIS as an integrating technology both for data and for different fields of science.

Complex adaptive systems occupy the core of the systems approach suggested by Clayton and Radcliffe (1996). This focuses on contingent, interactive, hierarchical, and dynamic systems, a set of characteristic behaviours that are intrinsic to many ecological systems, particularly at larger geographical scales. Complex adaptive system methodologies are being applied to diverse disciplines including economics, ecology (Breckling and Müller 1994; Jørgensen et al 1992), historical settlement and society, and environmental issues; however, they have yet to be applied directly to landscape conservation projects. A broad range of physical and social sciences (and their associated methods) need to be included in a systems approach to land use to develop the link between conservation and development implicit in sustainability. Relevant approaches include the Cartesian methods of the physical sciences (with themes of experimentation, laboratory control, repetition, and quantification), qualitative and historical methods of the social sciences (with themes of irreducible interaction, hierarchy, and resolvable contingency), and the spatial methods (Haggett 1979) and systems approaches (Chorley and Kennedy 1971) that are at the core of geographical science (Haggett 1979). Each of these approaches is well developed within the relevant physical and social science disciplines (see Couclelis, Chapter 2; Johnston, Chapter 3; Raper, Chapter 5). To develop GIS and models for applications in sustainability will require these disciplines to be linked while they retain their individual perspectives. Thus sustainability requires an inclusive approach and linkage between GIS and models should facilitate this communication and collaboration between disciplines.

4 LANDSCAPE AS SCENERY

A further important application of GIS in landscape studies is in the analysis of scenes. The usual method for using GIS to interpret scenic landscapes is through calculation of viewsheds based on the intervisibility of points on a digital elevation model (De Floriani and Magillo, Chapter 38; Fisher, Chapter 13). Miller et al (1992) assess the impact of land cover changes in the Cairngorm Mountains in Scotland by calculating viewsheds for selected viewpoints and for the whole study area through a visibility census. Davidson et al (1993) carry out similar analysis for siting power transmission lines across open landscapes on the Isle of Skye, Scotland in support of planning processes. This type of analysis is based on the 3-dimensional geometry of digital elevation data. Fisher (Chapter 13, 1991, 1992, 1993, 1994, 1996) and De Floriani et al (1994) examine the algorithms for viewshed estimation using GIS and associated accuracy issues.

An alternative approach to scenic appraisal uses the analysis of scene attributes to, for example, evaluate landscape quality (Appleton 1975). Harvey (1995) has addressed scenic appraisal through analysis of individual perception of landscape and wilderness using methods from cognitive psychology coupled with GIS to model the geographical consequences of these preferences. The study elucidates attributes that individuals and groups use to discriminate between landscapes, by identifying prototypical constructs that express the individual preferences. GIS is then used to map the juxtaposition of the preferred (and non-preferred) attributes as an expression of individual preference. This cognitive and perceptual approach appears to get much closer to the processes by which scenery is evaluated and individual choice expressed than approaches based on viewshed geometry. The process of landscape (scenic) evaluation usually contains a large subjective element (Appleton 1975). Use of cognitive methods developed in psychology (Kelly 1955), combined with analysis of landscape geometry and spatial analysis of attributes of scenic attraction, provides GIS with an important role in landscape assessment for scenic value.

There are two important general principles raised by these approaches to assessment of landscape as scenery. First, space is necessarily analysed as 3-dimensional since intervisibility is based on x, y, and elevation directions. This may be important in other applications. For example, the work on the analysis of habitats and landscape ecological modelling described above was based on the 2-dimensional (plan) model of spatial data exemplified by resource maps, although the vertical (architectural or structural) component of vegetation is known to influence the results of models (Flather et al 1992;

Lescourret and Genard 1994). The underlying terrain form in three dimensions will undoubtedly influence the value of the metrics used to describe patch shape, as well as other characteristics such as area, that are used by landscape ecologists. Anisotrophic effects may also be introduced into distance measurement, for example when direction or resistance to movement is influenced by landform. Wider landscape ecological and conservation applications of GIS may benefit from the emphasis on landscape as 3-dimensional. The evaluation of scenery also demonstrates the use of GIS to interpret behavioural preferences in a spatial context. This ability to represent individual views of landscape introduces the opportunity to explore semi-quantitative and other subjective, but personal, views within a spatial environment, potentially coupling the quantitative processing capabilities of GIS with a wide range of social and psychological methods (see Mark, Chapter 7). Although these are applied to human–computer interface problems they have been explored in geographical research (Unwin 1992), but little developed in relation to applications of information in GIS.

5 CONCLUSION

Kupfer (1995) reviews interrelationships between landscape ecology and biogeography as interest grows in identifying the influences of scale and heterogeneity on ecological processes; the particular perspective used is nature reserve design and management. The literature reviewed for this chapter shows that there is potentially a much more extensive linkage between geographical principles and landscape conservation, and that there is a practical need for this linkage given the emphasis on integrated resource management and planning provided by the concept of sustainability. GIS already provides techniques and opportunities for exploring diverse aspects of landscape conservation, but there are a number of developments that could be explored to provide reliable information to support decision-making. Not least of these is the use of GIS to develop insights into landscape conservation questions and issues from a range of perspectives beyond ecology and nature conservation. This review identifies a need to design GIS to develop these integrated applications and indicates some underlying principles of geographical and ecological understanding that will serve to structure the design. A systems approach is also presented as a mechanism enabling synthesis and within which the general understanding from geography and ecology can be integrated with perspectives from other scientific and social scientific disciplines. Landscape conservation appears to be moving from site-based protection for nature conservation towards an integrated and holistic approach to resource management directed at cooperating human and environmental systems. GIS clearly has a role in enabling this process.

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