Geographical Information Systems Applications in Ecology

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CONTENTS

1. ABSTRACT

GIS has a potential role in both theoretical and applied aspects of ecology. The use of GIS has accurately opened up whole new areas of ecological research and analysis. It is now possible to study and manage natural resources on a regional level, taking account of processes that were very difficult to study in small geographic areas. Digital map layers are also straightforward to query and can be used not only to ask where something is, but to speculate about why it might be there and not elsewhere. GIS can therefore be very helpful as a tool in conceptualizing problems or hypotheses in ecology. Ecological applications have been relatively slow to adopt GIS, but this has been partly because of the difficulties of collecting spatially certain field data. There are now some very good examples of GIS that have combined spatially referenced field data with data derived from other sources, including satellite imagery. The advantage of a GIS compared to a fixed map is the ability of the user to quickly modify the analysis by updating data, introducing new data, or changing the assumptions or locating a study area. Two cases study will be highlighted in this paper to show the importance of GIS technology for ecological studies and improving ecological analysis and decision making. In this paper, present some issues that the literature reviewed experiences and how to manage and modify the GIS application to fit for the ecological applications requirements.

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2. INTRODUCTION

Ecology is the study of how living organisms, including man, interact with their environment. In addition to the challenge of understanding ecological systems there are many pressing environmental problems facing the world today that demand better understanding of our own ecological role and impact. The important thing to remember is that good decision making depends in part on good information and the ability to interpret it. Because of the complexity of environmental systems, in this paper tends to study them using a reduction approach, focusing on small, discrete, simplified aspects. However, most environmental problems are multi-faceted and demand consideration of a diversity of information, issues and interests. This is where geographic information systems (GIS) come in. as we hope to demonstrate, GIS populate with the right data and models can help in the organization, interpretation and communication of ecological information in an efficient and effective manner.

3. OBJECTIVE

In this paper, I will discuss the benefits of the GIS in applied aspects of ecology and the type of data that can be used to run GIS in ecology.

4. REVIEW OF LITERATURES

In the early 1900s first systematic ecological studies which could be broken up into measurable components and mapped as layers (e.g., soil, geology, vegetation).This parametric approach was greatly aided with the breakthrough technology of aerial photography, which allowed people to observe, measure, and record separate parameters on ecological maps. the first institutions to make large-scale use of parametric mapping was the U.S. Soil Conservation Service, which thematically mapped soils and related natural factors as a way to spatially predict agricultural changes(Antenucci and et al.,1991).
The representation and analysis of land cover and land used are first touched by GIS applications for ecological related since the introduction of GIS application in the early 1970s (Tomlinson1, 1967, Coppock and Rhind 1991). In early 1980s the ecological application in GIS became one of the major area of GIS applications since the national and local government have developed a varity of datasets (Rydin 1994).
Many studies demonstrated the value of GIS as an important tool for assessing, managing, monitoring, analyzing ecological datasets in different disciplines such as the landscape level (Walker et al, 1987, Johnson et al 1988, Sebastini et al, 1989, Cocklin et al,1992), nature conservation (Bridgewater, 1993), biodiversity (Swanson, 1992), taxonomic organization from genetic to ecosystem (Gaston, 1991), the need for spatial and taxonomic data to support biodiversity action plans and provide GIS with important role in developing, managing , maintaining , and analyzing (Collar 1996, Ahearn et al 1990, Gaston 1994, Harrison 1995, Margules 1989), integration of biological records, inventory of resources (Saterdal and Birks 1993, Stoms and Estes 1993), the evaluation of geographical patterns of diversity (McKendry and Machlis 1991, Norton and Nix 1991, Scott et al 1993, Walker and Faith 1993), human activity with ecological quality for planning and management (Adams and Thomas 1996, Mwalyosi 1991) and there are many other studies have done almost in every part of ecology.

5. APPLICATIONS IN ECOLOGY AND CASE STUDIES

Many of the uses of GIS in the ecology will continue to be ordinary, involving more efficient capture, manipulation and display of data in conventional formats. However, the use of GIS opens up a variety of additional analytical opportunities and two cases studies will present in this paper in order to demonstrate the contribution of GIS.

A. GIS as a tool in conservation management

There are some examples where use of GIS has helped to explore multi-faceted conservation problems and to derive suitable management strategies. In one such example, GIS was used to explore the likely implications and effectiveness of a strategy to restore lowland wet grassland habitats in the UK by raising the soil water table. The UK's Ministry of Agriculture, Fisheries and Food (MAFF) has designated a number of Environmentally Sensitive Areas (ESAs) in which farmers are offered incentives to manage their land in a manner consistent with achievement of certain environmental objectives. A number of ESAs have significant areas of low land wet grassland, for which MAFF has prescribed agricultural and water-management operations intended to conserve of restore their distinctive wildlife (notably wading birds and certain characteristic vegetation communities). The implications of altering water levels depend on many interrelated factors that operate at a range of scales. Management prescriptions and financial incentives are uniform, rather than being tailored to suit different site conditions. Clearly, however, the implementation of uniform management on sites with very different soil types, management histories and current wildlife interest will have a variety of outcomes. To ensure prescribed management achieved an acceptable balance between ecological and agronomic object on different sites, evaluation of the effects of management was required. Without the benefit either of hindsight or of preparatory field research on the full range of potential sites, such evaluation was difficult. This case study shows how a GIS-based approach was used to model the outcomes of management on different sites and to resolve some of the conflicts of interest that can arise when attempting to manage for multiple land use objectives (Richard 1999).

The issues listed in appendix-1 illustrate the difficulties in prescribing management that would achieve both nature conservation and agronomic objectives on the same land (after Brown et al, in press).

One of the reasons why a GIS-based approach was used to evaluate management prescriptions was the fact that effective hydrological management (either for nature conservation or for effective farming) was rarely possible on a field-by field basis (Treweek et al. 1991). Not only can manipulation of water levels in one field have significant effects on hydrological conditions in adjacent field, but water supplies are increasingly threatened by demands from domestic and industrial users. This means that the availability of water needed to achieve target 'wetness regimes' often depends on water management throughout whole catchments. Furthermore, for mobile organisms such as birds and mammals, a matrix of habitat types may be necessary to satisfy habitat requirements throughout the year (Forman and Godron 1986). Therefore, while it might be possible to research the water requirements of individual species or communities through controlled experimentation in the laboratory or in the field, the results of such research cannot be applied without considering their spatial or landscape context.

Management of land for multiple objectives (in this case agronomic, ecological and economic) required strategies based on understanding of the mechanisms determining the likely outcomes of different management options.

The wetlands GIS was developed to:

-Assess links between distributions of wetland communities, hydrological regime and agricultural management; and

- predict the likely implications of alternative water management actions for both agricultural and ecological interest within defined test catchments.

A GIS-based approach had particular advantages over manual mapping in the areas of data organization and management as well as providing the opportunity for describing and modeling spatial relationships.

Information derived from field surveys was related to a base map. Color aerial photography was used to interpret land use and produce digital bound-arise that were imported directly into the GIS (a process that included orthocorrection of the aerial photography). Nine land use classes were interpreted from the aerial photography, with seven sub-classes: field boundaries, water-courses (stream/river, drainage channel), woodland (coniferous, broadleaved, mixed), scrubland, arable, grassland, ridge-and-furrow (arable, grassland), disturbed ground and wetland.

As the majority of the data were recorded at ‘field level’ field numbers were used as unique identifiers to link information held in the relational database with maps. Data drawn from the results of the field survey included:

- Plant species lists for individual fields (species presence/ absence).
- Mean percentage cover of 197 plant species in 220 fields.
- Plant species distribution maps for the study area.
- Vegetation community maps.
- Bird counts for selected fields.
- Dipwell data recording soil invertebrate biomass (potential food supply for birds).
- Sward height at the time of survey.
- Current agricultural land use and management.

To these field data, summary information on the known ecological requirements of particular species were added. For plants, for example, a system of indicator values developed by (Ellenberg 1988) was used to create a database of moisture (F) and fertility (N) indicator values for all the species recorded in the study area. This could be used as a basis for predicting plant species composition in unsurveyed fields, given knowledge of soil wetness or soil nitrogen levels.

The use of the wetlands GIS is best illustrated through and example that explains how maps and data could be interrogated. A number of bird species of nature conservation importance occur in lowland wet grassland, including snipe and lapwing. The feeding behavior and habitat requirements of these two species of wader differ. The wetlands GIS was used to establish which fields were used consistently by lapwing and snipe within the study area and then to determine whether the fields used consistently over the study period differed in terms of soil wetness of food availability.

Fields were classified as being used consistently if birds were present in at least two winters during the study period of three years. By querying the database of field survey information, it was found that distribution maps for the two species tended to be mutually exclusive, though both species apparently favoured riverside fields. The reasons for these distributions could be investigated through the relational database containing the characteristics of those fields used by snipe and lapwing. Preliminary examination of the habitat those preferences of snipe and lapwing in the study area suggested that snip and lapwing in the study area suggested that snipe were more frequent in the wetter fields, which were also rich in invertebrates, whereas lapwing appeared able to tolerate fields with low invertebrate abundance (Treweek et al 1994, Caldow and Pearson 1995). To examine these patterns further, recorded information on soil penetrability, soil wetness and invertebrate biomass was accessed and queried for the fields used by snip.

Recorded values for soil penetrability ranged from 0.0 to 9.01 with an average of 4.9 (measured in KgF) (higher values indicate that greater force is necessary to penetrate the soil surface and probe for invertebrates as food). The fields favoured by lapwing, rather than snipe, were those with drier, less penetrable soils and lower invertebrate biomass. Soil penetrability may not be as important for lapwings because they are near-surface feeders (reflected in their bill morphology), in contrast to snipe, which rely on an ability to probe the soil for invertebrate food supplies.

Differences between species distributions and preferences could be quantified by using a GIS-based approach that combined a relatively intensive field survey with the use of digitized aerial photography. Relationships between soil water table an species distribution could be explored, as well as the possible implications of altered soil wetness for agricultural land use . the results could be compared with those from related studies based on rigorous field survey and controlled laboratory experiments and also used to structure subsequent field surveys to best effect.

Note that effective communication of the results of such studies is vital if management decisions are to be improved. Many types of cartographic output can be generated from GIS, most frequently screen displays of the results of specific analyses. The output may displays (such as screen dumps) for insertion into other computer display packages such as desk-top mapping packages. These enable the wider dissemination of results in a visual form that demonstrates key findings effectively and makes them more accessible (Wadsworth et al.1999).

B. Measuring habitat distribution and re-distribution.

Cumulative habitat loss has become a problem for many species in many countries. Not only has the amount of wildlife habitat declined progressively, but its distribution patterns have altered. It is well known that the geographic location and spatial organization of habitat has a strong bearing on its accessibility and value to associated species. GIS technology has made it considerably easier to quantify those attributes of habitat distribution and organization that might affect habitat value and therefore to recognize when unacceptable thresh-olds of habitat loss and fragmentation may have been reached for particular species. Attributes of habitat availability and organization that might affect habitat value and that are amenable to measurement using GIS include:

- Amount or area of habitat (one or many types).
- Habitat isolation (distances between habitat area or ‘patches’ can be measured and compared with species dispersal distances).
- Edge: interior ratio (habitat may be more exposed to external influences including pollution, disturbance and invasion by uncharacteristic species).
- Habitat fragmentation 9 remaining habitat is in small, isolated units with higher edge: interior ratios).
- Average patch size (remaining habitat is in small units with higher edge: interior ratios- average patch size can be compared with minimum habitat area required to sustain different species).

Although areas can be measured on any map, measurements of habitat area remaining or lost are considerably easier using GIS. Not only can land-take be quantified, but the implications of different extents and types of habitat loss can be compared. If information is available about the relationship between habitats are, habitat quality and carrying capacity, it may be possible to predict the relative impacts of habitat loss for different species (Longley 1999).

6. SOURCE OF DATA

Ecological data sets often include both attributes (e.g. species name, vegetation class and growth stage) along with numerical measurements (e.g. temperature, pH and nutrient levels). Many such ecological measurements are recorded with reference to only two spatial dimensions, usually by means of the locational referencing system of the country within which the data are collected through use of local topographical maps to define location .in international data sets, however, latitude and longitude or the UTM grid are normally used. The vertical dimension (specified in terms of elevation above sea level) is often clearly recorded or is readily derivable from topographic maps. Measurements made within a soil profile will also require a depth dimension, but this is recorded with much greater resolution. The time of data acquisition will usually be recorded but continuously recorded time series outside climatological and hydrological datasets are uncommon. Data sets may be made available in highly aggregated forms, such as the presence or absence of species within grid cells of a specified size, origin and orientation.

In addition to measurement data, there are spatial data. An issue in the latter is the source data for habitat and vegetation mapping. This issue comes from the perspective of developing spatial analysis for 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 imposed spatial organization through the mapping process and this is then fixed for subsequent analyses in which it can exert a strong influence (Martin and Stoms 1992). In contrast, satellite imagery and digital air photography provide a surface of variation and can be used to investigate generalization and scale effects(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 continue field representation of ecological variation, remote sensing is an important data resource (Maguire 1991)

7. METHODOLOGY AND TOOLS OF STUDY

There is a Varity of ways of ways of representing ecological data in a GIS and no universal way. Ecological observations in a study area may be represented in a variety of ways:

A. a collection of irregular point samples, arising from randomly placed quadrates, the position of trees in a naturally regenerating wood or observation of an individual animal. (Note that by irregular we do imply that there is no pattern, only that it is not possible to exploit any geometric property of the pattern in the storage of the information.)

B. a collection of regular point samples, arising from systematically placed quadrates or transects.

C. lines delineating boundaries, arising from landscape surveys, or interpolated from point observations.

D. a regular grid, arising from remote sensing, within quadrate measurements or scanning existing maps.

E. polygons (lines drawn around the edge of a homogeneous patch). Homogeneous polygons may represent a quantitative or qualitative interpolation from observation points.

F. isolines (lines Joining equal values), in a process analogous to drawing contours you might draw isolines through point data to represent say biomass density or number of species.

G. triangular irregular networks, where the resultant surface might represent the same sort of phenomena as isolines.

Methods for representing data might also be influenced by the ways in which attributes can be expected to change. If you consider that an attribute is likely to show a gradual and even change over a study area, it might be preferable to represent it by using isolines. If, on the other hand, the attribute changes abruptly or in steps you might prefer to use polygons (Chrisman 1997).

8. 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 ecology 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, (Levin1992) 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 ecology is concerned with real-world locations and situations the importance of pattern and scale becomes highlighted and this emphasizes the need to couple ecological science with spatial concepts and methods (Hanski 1994). Ecology provides a conceptual framework for this coupling (Probst and Weinrich 1993) and GIS provides and obvious mechanism by which it may be achieved (Haines-Young et al 1993). The interaction of spatial and temporal scales, with each other and with phenomena at different levels of ecological organization, 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 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 organized with a hierarchical database based on spatial and temporal scaling of data sources and natural disturbance phenomena (Dlecourt and Delcourt 1988) and is used to analyze 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 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 ecology conservation. The close link emerging between landscape ecologist and GIS, and between spatial analysis and 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 applications(Longley 1999).

Aspinall (1995) reviews some of the opportunities for ecological research to benefit from spatial analysis with GIS. Johnson et al.(1988) reviews the role of spatial and process models in 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 (Johnston et al., 1988). The representation of ecological problems remains largely unknown, however, partly because ecology 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 and 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).

9. ISSUES OF USING GIS IN ECOLOGY.

Underlying the various issues concerning ecological data and GIS technology to handle it are questions concerning the organizational background: how quality of GIS representation, where should the database be sited and to whom should it be accessible and or what purposes?

1) Dimensions of linear features

. One issue was associated with the fact that dimensions of linear features like roads were often exaggerated to make them more prominent or visible on maps. Where paper maps are digitized for incorporation into a GIS. Locational inaccuracies are perpetuated, making it difficult to determine exactly where roads are located with respect to habitat or to calculate the actual area of land (or a wildlife habitat) that would be occupied or destroyed. To get round this problem, an alternative and perhaps more approach was tried, using data summarized at the 1km² level to estimate the overall potential or risk for habitat loss or fragmentation to occur, but this meant working with an artificial grid that the usefulness of GIS-based studies is severely compromised if the data going in are flawed in any way. On the other hand, the same applies to any ecological study, how ever it is carried out (Treweek et al., 1994).

2) Centralized versus distributed ecological database

The database is presently centralized at one site, but this need to be a model for other ecological databases in the longer term. There are three possible scenarios: all data at a central site, all data at many sites or some data across a range of sites with a grater of lesser degree of transparency in access to the user. Significant improvements in networking and communications technology over the past decade have provided direct access for users to many centralized database. The idea of many users having access to ecological data distributed across many databases is not yet, however, as realistic for a number of reasons. The requirement for multiple variable across large geographical areas can result in massive volumes of data for file transfer, and this may be complicated by the difficulties in processing some typical GIS operations over a network(particularly when complex graphics are involved)and the inexperience of many users in use of network technology. An alternative is to distribute the database of optical storage media for local access but this in turn raised problems of database update. The ever-decreasing cost of storage of data and economic possibility of repeat pressing at intervals may resolve this issue. Another alternative is that developments in data broadcast offer realistic longer-term prospects (Maguire 1991)

3) User access

Free and uncontrolled access to a centralized database is a technical possibility in reality; however, it is at present neither feasible nor desirable. Many users have only limited knowledge of the operation of a GIS and , without significant improvements in the user interface and /or user education, this is likely to pose a practical barrier to free access to the data. Other users, while technically capable of accessing the database, have only limited understanding of some of the issues of data quality noted above. Though it may be argued that it is not the duty of the database builder to prevent users from misusing the data, there are strong scientific, ethical and political reasons for doing so. For instance, many ecological issues are scientifically and politically very sensitive, misinterpretation of the data and results of analysed could lead either to establishment of inappropriate policies or to the discrediting of the whole information system, providing a justification fro suspending its implementation.
The access to the data can be via in-house, expert users only. This allows use of the data to be carefully regulated and inappropriate uses filtered out. It also offers the opportunity for education through discussion with users of the design of any data analysis or output, and the provision of advice of the most appropriate analytical techniques. A disadvantage is that it may deter use of the database of slow down access. More seriously, if not sensitively and openly implemented, it may amount to a form of data censorship, filtering out politically or administratively undesirable queries.
In long term, more open use of ecological databases may be achieved through the use of expert system, with their own built-in rules for data use. Unfortunately, while examples of such systems have been demonstrated (Scott et at.,1993) on the development of an expert system to support zoning of the Australian Great Barrier Reef), they are still some way from widespread operation and the rules which they can apply are only as good as the people who devise them
There is other example of such system in CORINE (Co-ordinated Information on the European environment) systems, this presents serious difficulties for the database is not yet in a sufficiently stable state nor is the management science yet sufficiently advanced to permit the application of the ‘hard and fast’ rules required of most expert systems. In particular, the user needs are not yet sufficiently understood to define the rules and the complex interaction between ecological variables remains inadequately understood (Maguire 1991).

10. CONCLUSION

GIS are not new to ecology science, but have been introduced into the profession during the last 15 years. Although the original ecology information was limited to spatial data, the recent developments in mapping technology , interpolation methods, remote sensing and modelling have provided ecological survey and environmental agencies with useful tools that are used for standard production of maps and reports and for research.

The role of GIS methods is described successively in estimation of the availability of natural resources, in improving the quality of data capture, in assisting visualization of changes, in applying physical models, in extrapolating and modeling changing environmental parameters through use of sample data, and in providing better access to ecological data.

10. RECOMMENDATIONS

Area of needing the technical development in the ecological database includes:

1. The development of scale-free databases (local, regional, national, continental and global scale).
2. The recognition and handling of error conditions in analysis and modeling (in the nature of much environmental data).
3. The development of icon-based interfaces to GIS to enable the wider use by an increasingly non-specialist audience.
4. Improving the accessibility of environmental databases.
5. Define and set up exchange formats for digital data.
6. Graphics-based spatial data retrieval, associated with automated graphic indexing.

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APPENDICES

Selected nature conservation and agronomic issues to be taken into account when prescribing management (Wadsworth et al.,1999).

Nature conservation issues

Do current hydrological conditions pose a threat to important species of communities?
Which species are currently most at risk and in what way/
Are these species unique to this area or are they widespread/
Will restoration of wet grassland biodiversity demand hydrological change?
Will proposed hydrological management create appropriate hydrological conditions for target species or communities? Which areas of land are most suitable for creation of appropriate hydrological conditions? Of those areas that are suitable, which are available for restoration?

Agronomic issues

Which areas of land would be eligible for ESA 'tier payments' (incentive payments) with little intervention or management change?
If hydrological conditions change, what are the implications for agricultural production? For example, will increased soil wetness demand changes in livestock management, machinery use or grassland harvesting dates?
Will productive potential be lost and will ESA payments compensate for lost profit?