INTEGRATING ECOLOGICAL TOOLS WITH GEOGRAPHIC INFORMATION SYSTEMS (GIS)

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ABSTRACT:

The world faces a wide variety of complex environmental threats: the loss of biodiversity; the depletion of the ozone layer; global climate change; the degradation of soil and water resources essential for food production; and the accumulation of widespread, health-threatening pollution. These problems are even further exacerbated by the basic trend in world population, which has doubled since 1950 and is expected to double again by the middle of the next century. The foremost global issue facing mankind is how to satisfy the ever-growing need for natural resources to meet food and living standard demands while minimizing impacts upon an environment which already shows signs of serious levels of biodegradation. Most sustainable development decisions are inherently multidisciplinary or cross-sectoral, because they require trade-offs between conflicting goals of different sectors. However, most natural resource development agencies are single-sector oriented. Geographic Information System (GIS) technology can help establish cross-sectoral communication - by providing not only very powerful tools for storage and analysis of multisectoral spatial and statistical data, but also by integrating databases of different sectors in the same format, structure and map projection in the GIS system. However, main constraints and problems drive with the current use of GIS in the Environmental Industry.

1. INTRODUCTION

The world faces a wide variety of complex environmental threats: the loss of biodiversity; the depletion of the ozone layer; global climate change; the degradation of soil and water resources essential for food production; and the accumulation of widespread, health-threatening pollution. These problems are even further exacerbated by the basic trend in world population, which has doubled since 1950 and is expected to double again by the middle of the next century. The foremost global issue facing mankind is how to satisfy the ever-growing need for natural resources to meet food and living standard demands while minimizing impacts upon an environment which already shows signs of serious levels of biodegradation.
Most sustainable development decisions are inherently multidisciplinary or cross-sectoral, because they require trade-offs between conflicting goals of different sectors. However, most natural resource development agencies are single-sector oriented. Geographic Information System (GIS) technology can help establish cross-sectoral communication - by providing not only very powerful tools for storage and analysis of multisectoral spatial and statistical data, but also by integrating databases of different sectors in the same format, structure and map projection in the GIS system (SDRN, 1999).

One of the most exciting and rapidly growing technologies for the 1990s is that of Geographic Information Systems[*1] (GIS). The computerized retrieval, manipulation, analysis, and display of geographic information allow experts in a variety of different disciplines to improve their effectiveness and efficiency when addressing location-related problems and issues. (Huxhold, 1994).

1.1 Overview

Using Geographic Information Systems (GIS) to explore the spatial relationships of animal populations is a relatively new field for ecologists (Johnson, 1990, Scott *et al.,* 1993) and one untouched by population geneticists. GIS, as an environmental modelling tool, evolved from simple beginnings as a mapping program to a modelling and analysis engine for a variety of different disciplines (Goodchild, 1993). GIS is well-established in habitat-based studies of animal populations to analyze remotely-sensed databases (Johnson and Naiman, 1990) and as a predictive tool for animal or plant species distributions (Scott *et al.,* 1993, Jensen *et al.,* 1992). In addition, GIS is now used to create databases, manipulate spatially-explicit surfaces to represent specific parameters, and to displace spatial relationships through simulation modelling, hydrologic constructs, and species relationships (Keller, 1990; Aspinall and Veitch, 1993). One application still unexplored with GIS, despite the importance of spatial heterogeneity, is the animal population dynamics as expressed by genetic parameters.

1.2 What is GIS?

A Geographic Information System (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on the earth. GIS integrates common database operations, such as query and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps (http://www.hgac.cog.tx.us/geography/cep/whatis.html). It consist of a powerful set of automated tools for collecting, retrieving, analyzing and communicating spatial data. Such systems involve not only the automated handling of map data and imagery, but also the automated handling of records and attributes of anything that can be tied to a geographical location on earth. The technology is applicable to remarkably diverse applications ranging from resource management to emergency response and disaster recovery, from political districting to forestry and marine studies, from mass marketing to urban infrastructure management, and from local studies through regional analysis to global change research (Raymond,

[1] Appendix 1

http://www.odyssey.ursus.maine.edu/gisweb/gisabout.html). Definitions can change rapidly and they vary according to who is giving them. The definitions of the early 1990s were functional in nature. They focused on what a GIS could do and what it would produce. Now definitions tend to address issues like "information strategies" and adding values to data. The range of views of GIS has increased over the last few years, in response to the expansion of the market for GIS and the applications to which it has been applied (Heywood *et al.*, 1998).

1.3 The Role of Geographic Information Systems (GIS)

When the habitat requirements of a species includes several factors, the information about habitat requirements may be combined by computer maps of each required habitat characteristic, using geographic information systems. This allows us to see the habitat patches as perceived by the species. In various case studies, we used this approach to model metapopulations of threatened species.

Current GIS applications in conservation biology and wildlife management include various aspects of habitat description, delineation and monitoring. Conservation biologists and wildlife managers are concerned with questions that involve predicting the future of endangered and threatened species (Akçakaya, 1992). Such questions include:

- Is it better to prohibit hunting or to provide more habitat for African elephants?
- Is captive breeding and reintroduction to natural habitat patches a viable strategy for conserving black-footed ferrets? If so, is it better to reintroduce 100 black-footed ferrets to one habitat patch or 50 each to two habitat patches?
- Is it worthwhile to relocate endangered helmeted honeyeaters from their current populations to empty habitat patches to spread the risk of local extinctions?
- Is it better to preserve one large fragment of old-growth forest, or several smaller fragments of the same total area?
- Is it better to add another habitat patch to the nature reserve system, or enhance habitat corridors to increase dispersal among existing patches?

To use GIS to determine the spatial structure with this approach, first it is necessary to distinguish the habitat characteristics important for the species. That can be done by collecting habitat and species occurrence data at a large number of locations in the landscape. The data then may be analyzed with multiple regression, which gives a function (called the habitat suitability function) that links the habitat characteristics to the suitability of the habitat. In the case of the helmeted honeyeater for example, the variables of this function will be the presence of ground water, density of *Eucalyptus* trees, and the amount of decortication of their bark (http://www.ramas.com/gisworld.htm).

1.4 Applications of GIS technology[2]

GIS are now used extensively in government, academic, non-profit and business for a wide range of environmental resource analysis and landuse planning applications. GIS technology employs computer software to link tabular databases to map graphics, allowing users to quickly visualize their data. This can be in the form of generating maps, on-line queries, producing reports, or performing spatial analysis (http://www.sara.nysed.gov/pubs/gis/sevencon.htm)

[2] See Appendix 2

2. THE MODEL

Preparing data for Animal Movement is relatively "easy". The program can directly utilize Point Shape files, which can import point data from delimited text, dBase files, SQL databases, and many CAD and GIS file structures. Each model consists of several elements:

1) A transforming surface - a GIS layer based on a single environmental feature such as elevation, streams, roads, etc.;
2) A weighting protocol - weights are assigned to each element on the transforming surface based on a preconceived concept on the ecological impact of that feature on animal dispersal;
3) A cost surface - a surface created by the GIS that defines each pixel on the transforming surface based on it's cumulative weight (cost) from a chosen starting point like a population center, to a specific endpoint; and
4) A dispersal path--a route drawn across the cost surface based on choosing the lowest cumulative cost to move between two specified points on that surface.

Digital databases to be used in the models include digital elevation model (DEM), digital line graph (DLG), vegetation (based on Soil Conservation Service DLG data), and landuse boundaries (http://www.absc.usgs.gov/glba/gistools/Anim_Mov_UseMe.pdf; http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/gillian_bowser/ncgia2.html).

2.1 Main Constraints and Problems[3] with the Current Use of GIS

(Brêtas, http://www.idrc.ca/books/focus/766/bretas.html)

2.1.1 Cost

Costs are currently the main constraint to the use of GIS. Software is relatively expensive in relation to the budgets. Expansion of GIS use will probably decrease its cost. In the meantime, a compromise would be to use available shareware, or to have a software tailored for use in control programs by a nonprofit organization.

2.1.2 Adequate Training

There exists at present a lack of trained personal. The new windowed interfaces, however, are easier to use and will speed up the process of training. Computing skills are useful in the labour market; consequently, staff from control programs should be willing to be trained.

2.1.3 GIGO (Garbage in, Garbage out)

GIS is not a tool designed to increase the quality of data. Frequently, much of the data collected is not used. GIS use could lead to a relaxation in data collection and consolidation. It is necessary to review all the steps in the information flow to guarantee quality and adequacy.

2.1.4 Misinformation and Misinterpretation

[3] Some other factors driving the Environmental Industry (http://www.esri.com/industries/environment/trends.html)

- Economic Uncertainty
- Pollution Prevention
- Cost and Services
- Federal Markets
- Commercial Markets
- Project Cost, Length, and Size
- Maturation

The powerful tools of GIS can easily lead to misinformation and misinterpretation, particularly by someone unfamiliar with their use. Ecological fallacies, problems of scales, and propagation of error are frequent, and should be given serious consideration. GIS is not a magical solution to all the information difficulties, but is a powerful tool capable of transforming the way with which information is dealt.

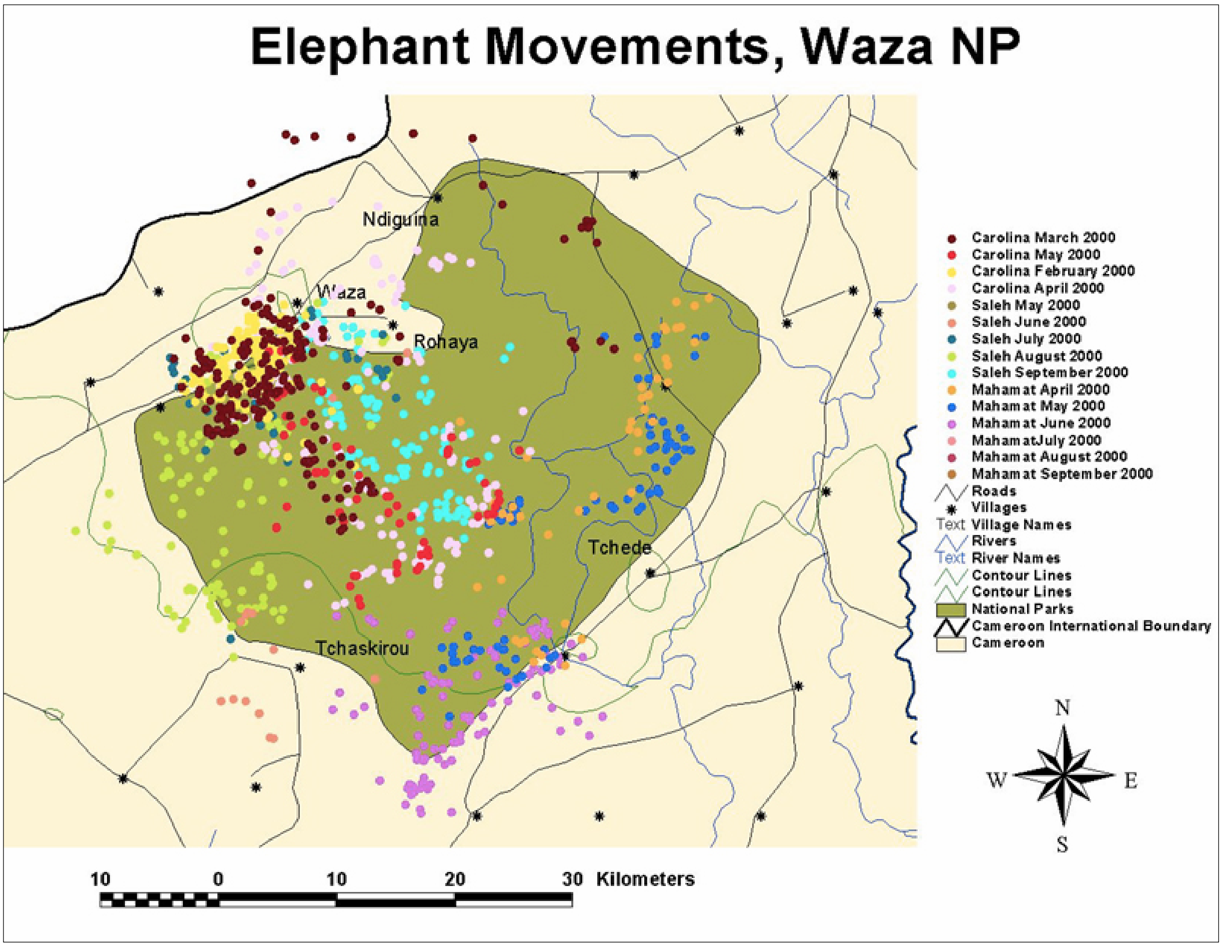


Figure 1: Elephant movements in Waza National Park – Cameroon[4] (http://www.nczooeletrack.org/elephants/loomis_maps/waza.html).

[4] *Method:* *Researchers attached satellite and radio transmitters to free-ranging elephants in Cameroon. The equipment monitored the elephants' activities during a five-year time span, providing data that recorded and analyzed to determine each herds habitat requirements and movement patterns. Radio transmitters allowed wildlife biologists to follow the elephants on the ground in the study areas.*
These data have been used to formulate strategies that allowed both elephants and people to maximize their sustainable use of these land areas. Data on the elephants' movements have been sent to WWF-Cameroon where it will be used to document the elephants' travel patterns and land use. This data will then be interpreted to identify areas where elephants should be protected and to develop strategies to assist elephants living outside of protected areas.

Environmental Applications of GIS	Contributing Disciplines to GIS	Where can you use GIS?
- Environment	- Landscape Ecology	- Anthropology
- Infrastructure and Utilities	- Geography	- Archaeology
- Business Marketing and Sales	- Cartography	- Atmospheric Science
- Computer Cartography	- Remote Sensing	- Meteorology
- Land Information	- Photogrammetry	- Botany
- Natural resources management	- Surveying	- Conservation
- Wildlife habitat modelling	- Geodesy	- Ecology
- Recreation resource management	- Statistics	- Environmental Science
- Floodplain management and flood control	- Operations Research	- Forestry
	- Computer Science	- Geography
- Wetlands restoration	- Mathematics	- Geology
- Aquifer and groundwater management	- Civil Engineering	- Historic Preservation
- Forest management		- History
- Coastal management		- Hydrology
- Fisheries management		- Marine Science/
		- Oceanography
		- Paleontology
		- Seismology
		- Soil Science
		- Zoology

Table 1: GIS as an Integrating Technology

An operational GIS also has a series of components that combine to make the system work. These components are critical to a successful GIS. A working GIS integrates five key components:

- **hardware,**
- **software,**
- **data,**
- **people,**
- **methods.**

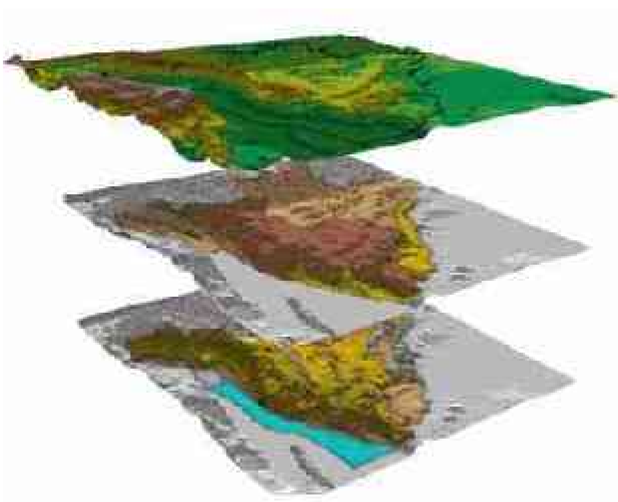
(The GIS PRIMER, http://www.innovativegis.com/education/primer/concepts.html)

<u>Figure 2:</u> Components of a GIS

CONCLUSION

Many governmental agencies and private organizations are beginning to use GIS to improve their services, assist in managing resources, and provide support for more informed decision making and policy planning activities. The applications of GIS technology seem endless because of the geographic nature of data used by so many different disciplines. Most GIS professionals will agree that GIS technology is truly a multidisciplinary resource that benefits a wide range of interests (Huxhold, 1994).

GIS is useful because drafting maps is easier, direct analysis of movements from GIS data is possible using the Animal Movement extension, visualization of trends (years, individuals, behaviors) is made easy, and query searches make finding the trends easy.



<u>APPENDIX 1:</u> Technical aspects of GIS and Tools Complementary to GIS

Some basic GIS functions

Essentially, GIS provides a means of taking many different kinds of information, processing it into compatible data sets, combining it, querying and displaying the results on a map. Some standard GIS capabilities include:

- Integrating maps based on different scales, map projections, or legends;
- Changing of scale, projections, legend, annotations, etc.;
- Overlaying different types of maps of a particular area to make a new map that combines the attributes of the individual maps. For example, a vegetation map could be overlaid on a soil map, as shown in the figure above. This in turn could be overlaid on a map showing length of growing season, thereby producing a land suitability map for a given crop;
- Generating buffer or proximity zones around lines or polygons on a map. This technique is used to find areas within a given distance from roads, rivers, etc., or from certain thematic conditions. These buffer zones can in turn be used as another layer in overlay operations;
- Querying spatial and attribute databases.

Satellite Remote Sensing

Satellite imagery in digital format allows for the acquisition of environmental data and land occupation patterns and features over large areas. Sensors in satellites record multispectral data from different wave bands in digital format. Different features of the terrain reflect differently in each waveband, allowing for their recognition in the images. The digital image is fed into the computer, where it is stored. The digital images can then be displayed and further processed to extract the desired information. They may also be integrated with other types of data and information within a GIS.

The information found within a digital image is contained in a grid constructed of spatial units called pixels. Each pixel number is related to color intensity and brightness. The main limitations of satellite images are cloud cover (Earth Resources Satellites pass over the tropical areas early in the morning, a period when clouds and mist are most prevalent) and resolution. Even with the best resolution available (pixels < 30 m), it is not possible to see houses, to adequately classify some types of agricultural practice, or to localize some breeding sites. Some of these problems may be circumvented using satellite navigation receivers.

By using the data from the different wave bands, it is possible to identify and track environmental characteristics. Vegetation, land-use patterns, surface waters, quality and humidity of the soil, roads, built-up areas, and climatic changes may all be monitored by satellite.

Satellite Navigation System (SNS)

The satellite navigation system (SNS) was originally designed to enable a user to obtain an instantaneous three-dimensional position, anywhere on the earth, at any time, under any weather condition. Clock information in satellites is emitted by radio wave.

The difference between the time when a message is sent and the time when the message is received allows for the calculation of the distance between the receiver and the satellites. Since the orbits of the satellites are known, exact positions can easily be calculated.

The SNS can be used in a number of ways to calculate absolute and relative positions with varying degrees of accuracy. The complete system consists of 24 satellites that are distributed in such a way that an adequate number of satellites is available for positioning at any given time.

When associated with a GIS, a SNS receiver is a powerful mapping tool. It can provide quick and accurate positioning of terrain features and dynamic mapping. The data received can be transferred to a computer and read by a GIS, where it is transformed into map format.

APPENDIX 2: GIS Applications

(http://www.geography.wisc.edu/sco/gis/applications.html)

- Environment
- Infrastructure and Utilities
- Business Marketing and Sales
- Computer Cartography
- Land Information

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