The application of GIS and Remote Sensing in phytosociology

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ABSTRACT. – The use of Geographical Information Systems and remote sensing techniques is spreading to most disciplines of geoscience. However, only in a limited number of cases have such modern tools been applied directly to phytosociological studies. In this paper, it is argued that the time has come to introduce these tools also in phytosociology. A short introduction to GIS and the most common types of remote sensing are therefore given, followed by a review of some studies where GIS and remote sensing have been applied in vegetation studies.

INTRODUCTION

Most phytosociological information is based on the relevé, a type sample, which is a static picture of a particular vegetation unit at a certain time and geographical location. By its very nature, such information is also geographical information, albeit from only one point in the temporal, spatial and environmental space. Usually, many such relevés are made in a study area, often in numbers of hundreds or thousands. Advanced methods for the classification and ordination of such data do exist, but the geographical analyses have been restricted to primitive dot maps, which although "geographical", do not offer the great possibilities of modelling, manipulating etc. as do the Geographical Information Systems (GIS) which are now available for microcomputers. Until now, very few datasets have been transferred into the logical geographical framework of a GIS. Admitted, it does take some time to establish and learn how to use GIS. Yet, all vegetation data are now usually by standard entered to a computer system, to be able to do statistical analyses, so the step further into the possibilities of GIS is only a short one. Most environmental data are rapidly being made available on geo-digitised overlays, so having the vegetation data in a similar format, enables the student of plant-syntaxon-environment relationships a unique possibility of overviewing spatial phenomena and processes, the physical environmental gradients, biophysical processes, relations of vegetation and climate, disturbance and vegetation conservation (Walsh & Davis 1994). The technology is robust, relatively cheap, flexible and user friendly (Schreier *et al.* 1990).

If the floristic and phytosociological data have been made available in a GIS system, the next and logical step is to compare and extrapolate the findings with a "true" picture of the Earth, in other words by means of a distant watch of the ground surface. This may be done from an observation tower, an aeroplane or satellite, which all represent examples of the tool with a rapidly increasing importance in all Earth related activities: Remote Sensing. The great advantages with remote sensing is its ability to cover large areas, repeatedly, which may be difficult to study, for economic or logistic reasons. Remote sensing ensures a regular and secure tool for monitoring and studying of natural phenomena, such as mapping of vegetation units, their distribution and interrelations, phenology, biodiversity, heterogeneity, connectedness, major disturbances such as fires, windfalls, stand-level die-backs, pest outbreaks, pollution impact, and many other themes, of which many are on the top priority agenda of national and international research institutions and environmental management boards. The results from the analyses of remotely sensed data may subsequently be entered into the GIS, and compared with other types of spatial data (Goodchild 1994).

GIS and remote sensing, with their many methods and facets thus constitute the most promising but also challenging possibility for mapping landscapes (Haines-Young 1992; Wickham & Norton1994), habitat types (Hodgson *et al.* 1988), determine scaledependence (Simmons *et al.* 1992; Benson & MacKenzie 1995) and for studies of vegetation and phytosociology.

About GIS

A geographical information system is designed for the input, storage, manipulation and output of geographically referenced data (Goodchild 1994), as defined by a three-dimensional dataspace with the point (x, y, z) where x and y define a place, and z is representing some information, such as the vegetation type. Any such dataset covering a particular area, and one parameter or variable could be called a layer in the GIS system. A fully developed GIS comprises many such layers.

Comprehensive introductions to GIS have been published by Maguire *et al.* (1991) and Star & Estes (1991). Yet, two fundamentally different ways of referencing geographical data should be mentioned here.

The above information z may be measured at a point, i.e. an infinitely small area. That could be the elevation above sealevel, atmospheric pressure or air temperature. For other types of geo-referenced data, the observation z is necessary to measure in an area, such as vegetation cover, vegetation type or heterogeneity, which can only be defined over a discrete area, which exceeds the area covered by any one individual organism.

These two types of data have resulted in two strategies for dealing with geographical data (Goodchild 1992): *a)* the fieldview, where a set of variables are recorded at each point, *b)* the entity view, where the concept is an empty space littered with various kinds of objects, with associated characteristics. The latter view is the most dominant one in everyday life, such as the topographic maps, while in science, both field and entity are used. In vegetation science, the field view is predominant, whereas in modelling, individual entities such as trees, in an empty space, are often used.

The representation of digitised information in GIS is simple for the entity type: points (individual trees in a plantation), points connected by a polyline (isobars in a meteorological atmospheric pressure chart), or points connected by a closed line, a polygon, and thus describing an area (the contours of a forest). This way of representing entities is usually called the vector format.

The digital representation of fields is usually done with a raster format, which may be a regular rectangular array of cells, with an aggregate value of the field recorded for each cell. If a forest is divided into one hectare squares, and these systematically all sampled, the resulting data would be of a raster type. Other common examples are the mapping of the distribution of plant species, as represented in grids, often 10x10 km, such as the Danish Atlas Flora Danica project.

Vegetation is usually mapped as fields (raster format) or as polygons (vector format). However, special types of vegetation or communities may be represented in more appropriate ways, such as linear features of a landscape, e.g. forest edge, road-side vegetation, or stream vegetation, which would be shown by polylines.

GIS represents an important tool in the management and inventory of plant distributions over large areas, such as aquatic macrophyte distributions (Remillard & Welch 1993), the analysis of historic landscape patterns, land-use changes and the associated changes in plant distributions (Kienast 1993).

Numerous studies of vegetation where GIS and remote sensing are used have been published lately. A few could be mentioned to illustrate the types of studies where GIS is applied, and where even phytosociological themes would be relevant.

By mapping and analysing snow accumulation patterns in Montana, USA, Walsh *et al.* (1994) were able to model and forecast the occurrence of different vegetation types and structures (easily convertible to at least alliances) ranging from closed forest to meadows, krummholz and unvegetated surfaces. Davis *et al.* (1994) used GIS in combination with remote sensing to characterise the coastal sage scrub vegetation in S. California, and assess its status. Hodgson *et al.* (1988) produced maps of the wetland habitats for the Wood Stork in southeastern US, by the combined use of remote sensing and GIS.

About remote sensing

Any kind of observation of an object, at a distance, such as the human eye, would be called remote sensing, but usually its meaning is restricted to information obtained by man-made devices (e.g. aircraft or satellites) recording information from a part of the electromagnetic spectrum (Clarke 1986). Remote sensing of the Earth has generally been restricted to wavelengths which are either strongly emitted or reflected from the Earth. The sensors used for remote sensing are either passive such as a camera, which records the radiation from a target on the ground, or active, such as radars, which generate their own illumination, and form the image from reflected signals of the objects on the ground.

Aircraft is an important platform for observation of the Earth, and has maintained the important position for high-detailed sensing with visible and infra-red photography, video and MSS (multispectral scanners). The resolution (pixel size) may be less than 1 metre. Lately, the use of airborne SAR (Synthetic Aperture Radar) for ground observation has gained much importance, as it is unaffected by clouds, fog and precipitation, which often make conventional visible recording impossible. However, some technical developments in the sensor systems and the image processing are still needed in order to obtain the maximum benefit of this very promising technology in geoscience, vegetation science and phytosociology. Few papers have therefore appeared in this field, and mostly dealing with forests. Sader (1987) used SAR for determining forest structure and species relationships, while Ranson & Sun (1994), carried out forest classification in northern USA, achieving a 80% accuracy of hardwood, softwood, regeneration and clearings. Bogs, wetlands, grass and water areas were also well classified.

Satellites are most commonly associated with remote sensing, and indeed many satellites have been positioned in orbit around the Earth (e.g. Meteosat, NOAA, Landsat, SPOT, ERS-1), which provide safe, regular and relatively cheap observations of the Earth. The satellite may be the platform for the spaceborne variant of SAR, which is the case with systems such as Seasat, SIR-A, SIR-B, and the presently active ERS-1. However, most satellites have been used for MSS, such as the Landsat satellite programme, in which four areas of the spectrum are recorded continuously, i.e. two parts in the visible and two parts in the infra-red spectrum. A further improvement is the Thematic Mapper (TM) of the Landsat-4 and -5 satellites, where a more precise measurement of 7 narrow bands ensures a better resolution, of approximately 30 m (Belward *et al.* 1990). The Thematic Mapper has gained wide use in vegetation studies. The SPOT satellite records data in a panchromatic mode and in a MSS mode, much similar to Landsat, but with a better resolution. Similar configurations are present also in the NOAA satellite. Many textbooks (e.g. Curran 1985) and journal papers have been published, dealing with the application and interpretation of satellite imagery, applicable to vegetation science and phytosociology. Only a few of these will be mentioned here.

Frederiksen & Lawesson (1992) studied general vegetation or formation types in Senegal by means of multitemporal NOAA imagery with a 1 km resolution, and extensive ground data, which were combined by multivariate analyses. The method showed a high degree of accuracy, and a map of Senegal with formation types was produced. The indicated types were not described in a formal way, but were at the alliance level, if considered in a phytosociological context. In another, more extensive study, Stone *et al.* (1994), by means of vegetation maps, phenology and visual interpretation of NOAA imagery, produced a vegetation map of South America, and the area covered by 39 different classes of vegetation was detected, such as tropical moist forest, savanna, cool deciduous woodlands and montane forests, just to mention a few. Ripple (1994) determined coniferous forest cover and forest fragmentation, with the use of NOAA and Landsat MSS imagery, in northwestern USA. A map of Oregon was produced showing the extent of closed canopy cover in each picture cell. A good correlation with the successional stage in the forest was also found. Iverson *et al.* (1994), studied forest cover in eastern USA, by combining NOAA and Landsat TM imagery. Good correlations between remotely sensed data and ground data were achieved.

A number of papers using the Landsat TM and MSS has been published on the Land Cover Map of Great Britain or closely related topics (Belward *et al.* 1990; Fuller & Parsell 1989,1990) in which many types of vegetation have been mapped and monitored by means of the Landsat TM. Fuller *et al.* (1994) for instance, distinguished 25 cover types, such as bracken, grassmoor, lowland bog, open shrub heath, deciduous/mixed woodland etc., all equivalent to current syntaxonomical units, but not necessarily without problems as relates to conventional vegetation classifications (for a critical comparison and discussion see Cherrill *et al.* 1995).

Finally the paper by Baker *et al.* (1991) could be mentioned as an example of the application of SPOT high resolution imagery to map seminatural agricultural land cover in two locations in UK.

Conclusion

The possibilities of Geographical Information Systems and remote sensing have been described in general in this paper. It seems evident, that many research topics, currently under study in phytosociology, could and should be analysed by means of these techniques. The major fields in which to apply GIS and remote sensing would be survey, mapping, monitoring and subsequently modelling (Brown 1994; Neilson & Marks 1994).

As concerns phytosociological surveys on a larger scale, one could mention the ambitious Vegetation Survey of Europe, shortly to release a new map of the potential vegetation types (in general the alliances) of Europe, which in its digitised form could be a most important GIS layer, to be used with other layers on biology and the environment, and furthermore be a valuable check reference for the future vegetation maps of Europe produced with remotely sensed data.

Still, in certain regions of Europe and within particular groups of syntaxa much data collection, treatment, mapping and understanding of the environmental context are needed. One such example could be Scandinavia. The systematic collection and recording of past and new relevés are about to begin, so a general overview in terms of the data themselves, their geographical and taxonomic coverage and their relationships with historical and present day distribution of vegetation types, or alliances, associations and other GIS-layers would be greatly enhanced by the introduction of GIS and remote sensing. In this way, areas of special interest, or those which are poorly known, would be apparent after the analyses, and the few and limited resources for data collection on vegetation and biophysical properties could be spent in an effective and profiting way. GIS and remote sensing products may thus provide guidelines for vegetation sampling and surveys (Michaelsen *et al.*1994).

In the field of monitoring, this implies the regular watch of natural phenomena in larger areas, studies which are almost only possible by means of remote sensing. Remote sensing of vegetation usually involves an implicit link to the phenology of the vegetation under study, and is thus an important tool for ecosystem monitoring, as reported by Reed *et al.* (1994) where the variation in phenology has been followed in USA.

In Europe, the extent and development of different vegetation types (on the level of alliances or associations) could readily be followed, such as the forest alliances, major grassland associations, wetlands etc. By applying multitemporal imagery, changes in status or distribution may be detected.

In a test area in Jutland, Denmark, NERI is studying the phenology of a wide set of vegetation types, by means of GIS, SPOT and SAR products and applying these to vegetation classification, mapping and modelling.

NERI is responsible for monitoring of terrestrial plants and animals, and it would also be natural to include syntaxa of plants. A number of GIS layers is therefore being prepared, to include all terrestrial and limnic syntaxa. This would be the first step of monitoring Danish syntaxa and their status. In this work, extensive use of all available GIS layers on the bio-environment, airborne SAR and MSS from particularly interesting areas, and SPOT and Landsat scenes covering larger areas are currently processed and analysed. A national yearly vegetation map with at least certain syntaxa would be one of the products.

These final remarks hopefully elucidate the great potential of GIS and remote sensing in vegetation science in general, and in phytosociological studies as well. NERI will continue to pursue the introduction of these methods in the projects in which we are involved, such as biodiversity and vegetation studies in grasslands and old-growth forest, in sustainable forestry and more generally in our wildlife and landscape ecology projects.

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