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VEGETATION MAPPING USING DIGITAL COLOUR ORTHOIMAGES: A NEW METHODOLOGY

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RESUM

Es presenta el disseny d'un mètode per a la realització de mapes de vegetació o forestals o d'usos del sòl utilitzant tècniques de cartografia digital basades en ortoimatges en color i la fotointerpretació sobre la pantalla de l'ordinador a escala de detall, combinades amb treball de camp. Aquest mètode ha estat assajat en l'elaboració del mapa de la vegetació del Parc Natural de la Zona Volcànica de la Garrotxa (Girona) durant l'estiu de 1995. La cartografia obtinguda amb aquest mètode pot ser incorporada a un sistema d'informació geogràfica de manera que pugui ser manipulada, consultada i analitzada amb facilitat. El mètode permet obtenir mapes de molt elevada precisió sense haver d'invertir en equipaments d'alt cost.

RESUMEN

Se presenta el diseño de un método para la realización de mapas de vegetación o forestales o de usos del suelo utilizando técnicas de cartografía digital basadas en ortoimágenes en color y fotointerpretación sobre la pantalla del ordenador a escala de detalle, combinado con trabajo de campo. Dicho método se ha ensayado en la elaboración de un mapa de la vegetación del Parque Natural de la Zona Volcánica de la Garrotxa (Gerona) durante el verano de 1995. La cartografía obtenida con este método se puede incorporar a un sistema de información geográfica de forma que pueda ser manipulada, consultada y analizada con facilidad. El método permite obtener mapas de elevada precisión sin tener que invertir en equipos de alto coste.

ABSTRACT

This paper presents the design of a methodology to obtain vegetation, forest or land use maps; the technique is based on digital colour orthoimages and detailed on-screen photointerpretation combined with field work. This method has been tried in the elaboration of a vegetation map of the Garrotxa Volcanic Zone Natural Park (Girona), summer 1995. The map obtained by this method can be incorporated in a Geographical Information System to enable ready manipulation, query, and analysis of the information. The method allows high accuracy maps to be obtained without using high cost equipment.

Keywords: Vegetation mapping, protected land, orthophotomap, land use, Geographical Information System.

INTRODUCTION AND OBJECTIVES

Our need to understand the natural environment has led to the development of different disciplines of study, for example geology, biology or geography. Each aims to classify the many abiotic, biotic or human-related factors so that their components and the relationship between them can be established. This requisite has led to the creation of various methodologies to represent the information collected from the natural environment, such as thematic cartography, phytosociological relevés, vegetation transects, edaphological profiles etc. Cartography is one of the most widely used methods to represent the environment, even though it wasn't until the beginning of this century, with the advent of modern photogrametry, that precision in cartographic production became possible (MIRANDA, 1990).

Cartography as a speciality can be divided into two fields: topographic and thematic. Thematic cartography is defined (OZENDA 1986) as an operation consisting of transcribing a supplementary phenomenon, which constitutes the theme, over a topographic base where relief, hydrography, places, roads, or any part of these are featured. It can therefore be defined as the planimetric representation of a more or less abstract concept of the natural environment, which can be identified as a specific and real object and which is traced over an analogic or digital georeferenced support.

In 1950, BOLOS suggested an acceleration in the development of vegetation representation techniques and noted the few vegetation maps previously existent in Catalonia. Even though some time has elapsed, this type of map is still at a basic stage and the surface area mapped in any detail is very limited (PANAREDA & PINTO, 1990).

From 1970-80 the gradual introduction of computers as a mapping tool and the improvement in photogrametry techniques, both in surface capture as information storage information has facilitated the acquisition of territorial data for studies in the civil field (MIRANDA, 1990).

One of the most important advances has been the development of new image capture techniques from remote sensors, either in satellites (LANDSAT TM, SPOT HRV, etc.) or airborne (AVIRIS, CASI, etc.). These techniques have allowed a rapid and often regular collection of spatial information that has demonstrated its application to cartography (VIÑAS & BAULIES, 1995).

These improvements in the field of cartography have allowed classical methods of vegetation mapping to evolve towards an optimum planimetric representation, with greater quantity and quality of information. This generates, however, the problem of data manipulation. Nowadays, it is practically essential to represent thematic cartography digitally and within a Geographical Information System (GIS) (that is in a georeferenced form and with the possibility of interrelation with other sources of spatial information). The development of the GIS, particularly in this decade, means any study that includes spatial data collection must be designed with storage of the data in mind. This should be in a georeferenced database system allowing ready manipulation, management, query and analysis of the information.

Present-day environmental management often requires highly detailed cartography for planning and decision-making at a local level. More general maps, although valuable for an overall vision, are inadequate and more precise representations are required.

Such considerations led to the development of this study with two main objectives:

a) To design a working method to produce vegetation, forest or land use maps using digital cartographical methods based on colour orthoimages and detailed on-screen photointerpretation.

b) To evaluate this in practice by elaborating a vegetation map of the Garrotxa Volcanic Zone Natural Park (GVZNP).

Geographical Situation

The GVZNP is situated in northeast Catalonia, in the centre of the Garrotxa region, in the rectangle with coordinates UTM-31N: 454 4660 and 468 4675 (Figure 1). GVZNP is in the Borough of Olot, characterised by quartenary volcanism (FERNANDEZ, 1991) and lying between part of the upper basins of the Fluvià, Sert, Brugent and Llèmana rivers which are separated by the Corb and Finestres mountain ranges.

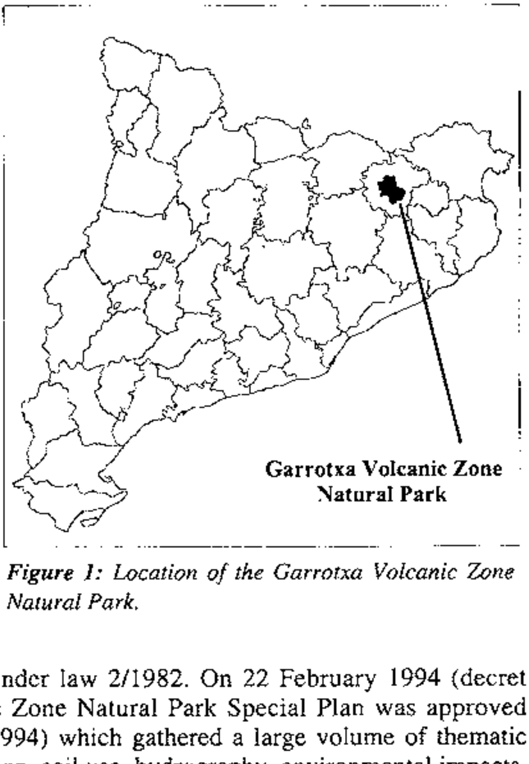

Figure 1: Location of the Garrotxa Volcanic Zone Natural Park.

The Volcanic Zone was declared a Natural Site of National Interest, with geobotanical reserves, by the local government (Generalitat de Catalunya) on 3 March 1982, under law 2/1982. On 22 February 1994 (decret 82/1994) the Garrotxa Volcanic Zone Natural Park Special Plan was approved (GENERALITAT DE CATALUNYA, 1994) which gathered a large volume of thematic information on lithology, vegetation, soil use, hydrography, environmental impacts, etc.

Previous vegetation cartography at GVZNP

Apart from its geological importance, the Olot area has a diverse/rich landscape and flora and has been the centre of botanical and vegetation studies since the end of the XIX Century. Celebrated naturalists and scientists such as Francesc Xavier de Bolòs, Pietro Bubani, Estanislau Vayreda, Ramon de Bolòs, Antoni de Bolòs have studied the Volcanic Zone natural environment. There are more recent studies by O. de Bolòs, J. M. Mallarach, M. Riera and X. Viñas, amongst others.

In recent years, several authors have mapped the vegetation of certain areas of the Park; MALLARACH & RIERA (1981) and RIERA (1986) from a physiognomical perspective and BOLOS & MASALLES (1983) and VIÑAS (1993) adopted a botanical approach. These maps, however, do not cover the entire Park area and are general scale with little detail. There is also a vegetation map created for the GVZ Special Plan (GENERALITAT DE CATALUNYA, 1994), at a scale of approx. 1:38000. While being more detailed, this has a general legend that gives no precise information on the vegetation. Other cartographic work on vegetation including the Park, or part of it, are maps with relatively little detail, generally at a scale of 1:50000 or more general. We find, therefore, that there is no vegetation map covering the whole Park area with a detailed scale and legend and which allows interpretation of dynamic aspects of the vegetation. Thus it is clear that a vegetation map on a detailed scale and with a botanical legend would considerably enhance the existing knowledge of the flora and vegetation of the region (BOLOS & BOLOS, 1987).

MATERIAL AND METHODS

1. Cartographic material

The principal sources of data used in this study correspond to two cartographic products: the 1:10000 colour photograms of the GVZNP taken during flights in spring 1993, in which most photographs were taken in May (the rest in July), and the digital orthophotomaps of 2.5 m resolution (taken in July and August 1993) produced by the Institut Cartogràfic de Catalunya (ICC) and ceded by the Departament de Medi Ambient (Department of the Environment) of the Catalan government to enable this study to be carried out (1:25000 sheet numbers 294-II, 295-I, 256-IV and 257-III from the Instituto Geográfico Nacional [National Geographic Institute], series).

In addition, the topographic maps 294-II [Sant Privat d'en Bas], 295-I [Santa Pau], 256-IV [Riudaura] and 257-III [Olot] of the "Mapa Topográfico Nacional de España 1:25000" series, published by MOPU and the Instituto Geográfico Nacional, were used as well as maps I-4: [Lithology (series 2)] and I-7: [Vegetation (series 2)] scale approx. 1:38000 created for the GVZNP Special Plan (GENERALITAT DE CATALUNYA,1994) in digital and paper support (CAMPOS & PONS, 1994), and the vegetation maps by BOLOS & MASALLES (1983) and VIÑAS (1993).

2. Computer Equipment

The computer equipment used in this study consists of 486 or more modern computers with high definition screens and high hard disk capacity (1 Gbyte or greater), a CD-ROM reader, a digitizing tablet and a plotter. Other apparatus used included a mirror stereoscope, a GPS receiver and various material common in field work.

The main software used were the programmes MiraMon v.1 (www.creaf.uab.es), Idrisi v.4, AutoCad v.12 and other programmes developed by PONS (1992) which allow treatment and manipulation of files and their transfer to different programmes.

3. *Methods*

3.1 - Former methodologies

Traditional botanical cartography is based on three principal aspects: photointerpretation of vegetation units over ancillary photographs (aerial photographs in black and white, colour or colour infrared, reconstruction of the photointerpreted units over topographic maps (assigning features to as many polygons as possible), and identification of unlabelled polygons and confirmation of those already determined by field work (KÜCHLER & ZONNEVELD, 1988; BOLOS & MASALLES, 1983; VIÑAS, 1993).

To date, the most commonly used images for photointerpretation were black-and white photographs, for reasons of cost and availability. The use of preexisting photograms presents several difficulties. The images are often in black and white, which have less scope for photointerpretation than colour or false colour photographs. They are usually taken at unsuitable times of the year for physiognomic vegetation study and rarely correspond to the year for which the map is intended. A third problem is the scale which, when small (for example 1:60000), impedes the elaboration of large scale maps (for example 1:10000). It is well known that, with the aid of a stereoscope, vertical aerial photographs allow a three dimensional view of the terrain. This aids interpretation of the relief and vegetation textures and allows mountain slopes and large phytotopographical units to be differentiated which is one of the most interesting characteristics of this type of material.

Reconstruction of the boundaries between the different elements identified is often not done precisely (there is always some distance or "jump" between the photograph and the topographic map) often producing considerable planimetric error. Although simultaneous reconstruction tools exist which solve this problem, elevated cost has restricted their use by vegetation cartographic groups. The usual solution is to work at a larger scale than that of the final map representation, so that the level of error is acceptable.

Finally, checking the validity of the polygons assigned in the laboratory is done by field work, which is more or less intensive according to the basic material, type of legend and final map scale.

3.2 - Methodological proposal

The methodological protocol followed can be divided into three blocks (Figure 2):

a.- Preparation of digital material and photointerpretation.

A mosaic of the study area was prepared from the digital colour orthophotomaps. In our case, an image consisting of four fragments was formed which covered the entire park area. These were mosaiked to form a mosaic over a common raster grid, as the original files had different cell origin. As this file is georeferenced it gives precise access to each point of interest. The computer may also have other, complementary, map layers simultaneously on the screen such as basic topography or lithology, which aid the integration process (types of relief, lithological limits,

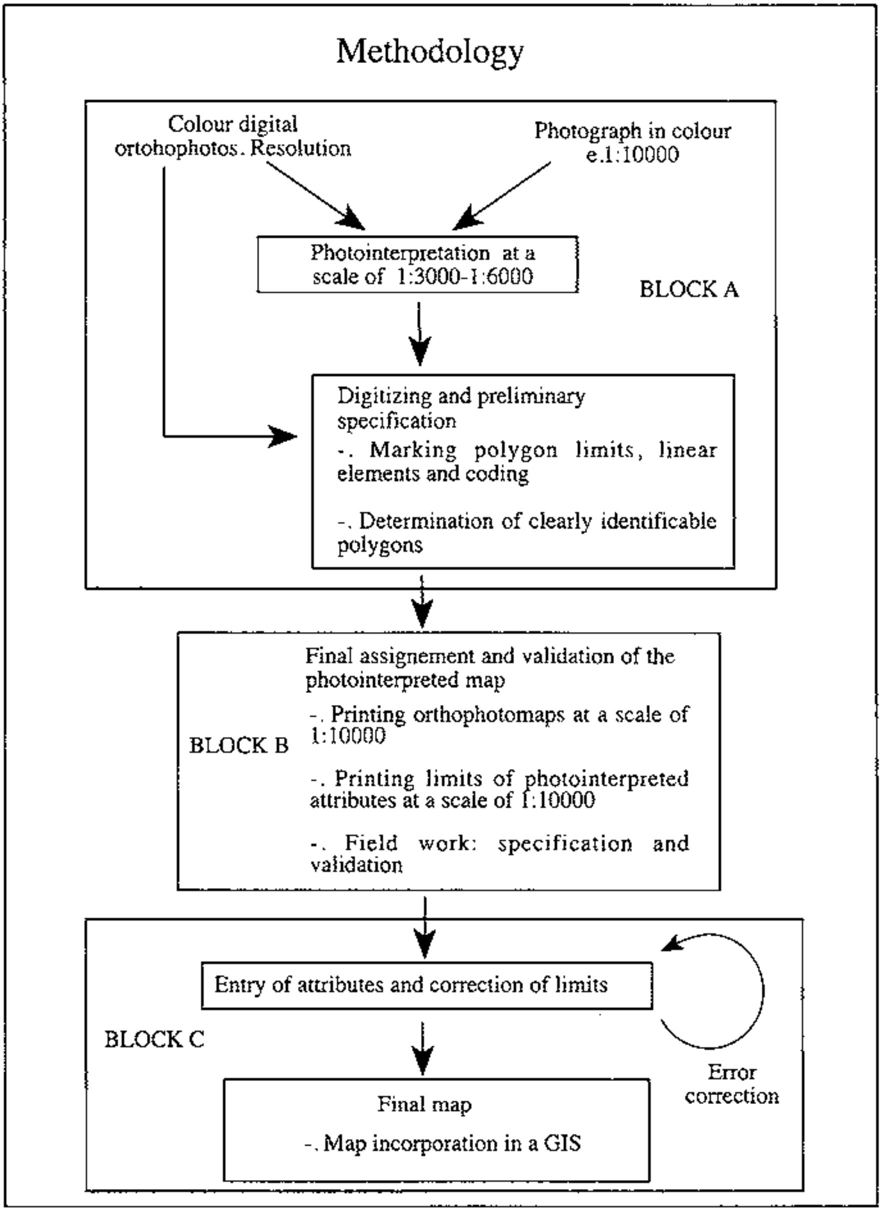

Figura 2: Methodological protocol used in the elaboration of the GVZNP digital map.

infrastructure-road limits that can be used or copied, etc.). It should be remembered that this material requires considerable disk space (39 Mbytes for each RGB band in our case).

Once the digital material is prepared, photointerpretation can start, with the complementary use of the original photographs (and with the aid of a table stereoscope). In our case these were 1:10000 colour photographs and were more detailed than those used to generate the orthophotographs. The operator identified all textures, colours, objects...classifiable as individual cartographic units at the working scale. Each one of these objects, or homogenous units, was traced over the digital orthoimage visualised simultaneously on the computer screen. Each of the identified limits was traced using various drawing tools from the software employed (MiraMon). This phase of the process is one of the innovative parts of this study; the information interpreted from the aerial photograph is transcribed to a detailed digital base (which is georeferenced and has a low planimetric error) at a digitalization scale of approx. 1:3000 and with a visual reconstruction process less prone to errors than reconstruction over conventional topographical maps. Of course there are photogrametric devices to do this task, but their cost is usually too high for thematic mapping purposes. The area considered minimum during photointerpretation was 500 m^2, even though elements of lesser dimensions were marked in some cases (always greater than 150 m^2) such as rural constructions, small wood glades etc.

Given the nature of the vegetation units different labels were assigned to the type of line or limit during photointerpretation. These were:

-. *Sharp boundary label:* indicates lines that correspond to clearly identifiable limits, named sharp boundaries (between woods and crops, cities and woods, etc.).

-. *Fuzzy boundary label:* indicates indistinct boundaries where the line separating one polygon from another is not perfectly clear. This problem occurs because the vegetation often does not change abruptly from one unit to another but rather varies gradually. Recognising these two types of boundaries is particularly important with regard to consultation of the map generated and posterior use in studies of vegetation dynamics, when comparing with data from remote sensing, etc.

-. *Linear category label:* attributes corresponding to vegetation associations with a linear distribution that do not have, at the working scale, sufficient surface area to be represented by a polygon. Some examples are field margins, dry walls, water channels etc.

The information digitized at this stage is stored in a vector file. This file can be transferred later to a DXF format to be edited, if needed, using CAD programmes.

b.- Preparation of material and validation of the polygons in the field.

Once photointerpreted, the orthomaps and the photointerpreted limits are printed separately to carry out the field work. In our case, the 30 sections that the Park occupies at a scale of 1:10000 were printed on A3 sheets. The photointerpreted limits were printed separately on A3 transparent acetate to superimpose the polygon limits on the orthoimages. To aid overlay, the 1 km UTM grid was also printed as a visual reference. The images proved extremely useful as field guides to the area. Field work was carried out in summer 1995.

Using this material in the field, the unidentified polygons were labelled and the labelled delimited polygons from photointerpretation validated. The level of complexity of the legend meant each polygon had to be visited separately to correctly determine its category.

c.- Entering the attributes and error correction

Once the field work was finalized, the data was entered assigning a numeric value (that of legend category) to each limit or unlabelled polygon, the erroneous labels were corrected and badly interpreted limits redrawn. The correction process was aided by placing the acetates over the digitizing table, georeferencing and thus obtaining direct access to all elements (labels and lines) to be corrected.

Once this process is finished, the whole map must be revised to detect any errors such as missing labels or false polygons, etc. which are difficult to detect by the operator. A topological structure or a transfer of polygons and attributes to raster format may be chosen to achieve this (CAMPOS et al., 1995).

The definitive digital map, in vector or raster form, is transferred to a Geographical Information System to consult and quantify the different categories identified and to link information contained in the map with other variables such as the digital relief model, slope map, lithological map, etc.

RESULTS AND DISCUSSION

The main result of this study is a digital vegetation map. The following methodological points were observed during the production process:

With regard to photointerpretation over the aerial photographs taken by the Park, the scale (1:10000), colour and quality made them extremely useful for precise identification of polygon limits in the laboratory. There were, consequently, few delimitation errors in the field. Furthermore, polygons were identified that otherwise would not have been detected. The photographs taken in May had a better contrast/resolution of the different vegetation units than those taken in July, for example, the holm-oak groves were clearly differenciated by colour and texture from the flowering masses of *Robinia pseudoacacia* and other deciduous masses, and oak distinguished from the chestnut and beech forests by texture. These photographs enabled many polygons to be precisely identified that otherwise would not have been detected. The availability of this material has also allowed a better delimitation of indistinct boundaries and shorter validation and correction phases.

With respect to the digital orthophotomaps, the 2.5 m pixel resolution and the colour were useful for photointerpretation and for tracing (reconstructing) those cartographic units identified (Figure 3). The working scale used during reconstruction will depend upon the size of the elements to be delimited and the complexity of the area; for example, in the case of a highly diverse mosaic the scale would be approx. 1:3000, while with extensive homogenous forest a scale of 1:6000 could be used, bearing in mind that these areas delimited at a smaller scale are polygons of the fuzzy boundary type. The time taken for photinterpretation of an A3 sheet containing information from a 1:10000

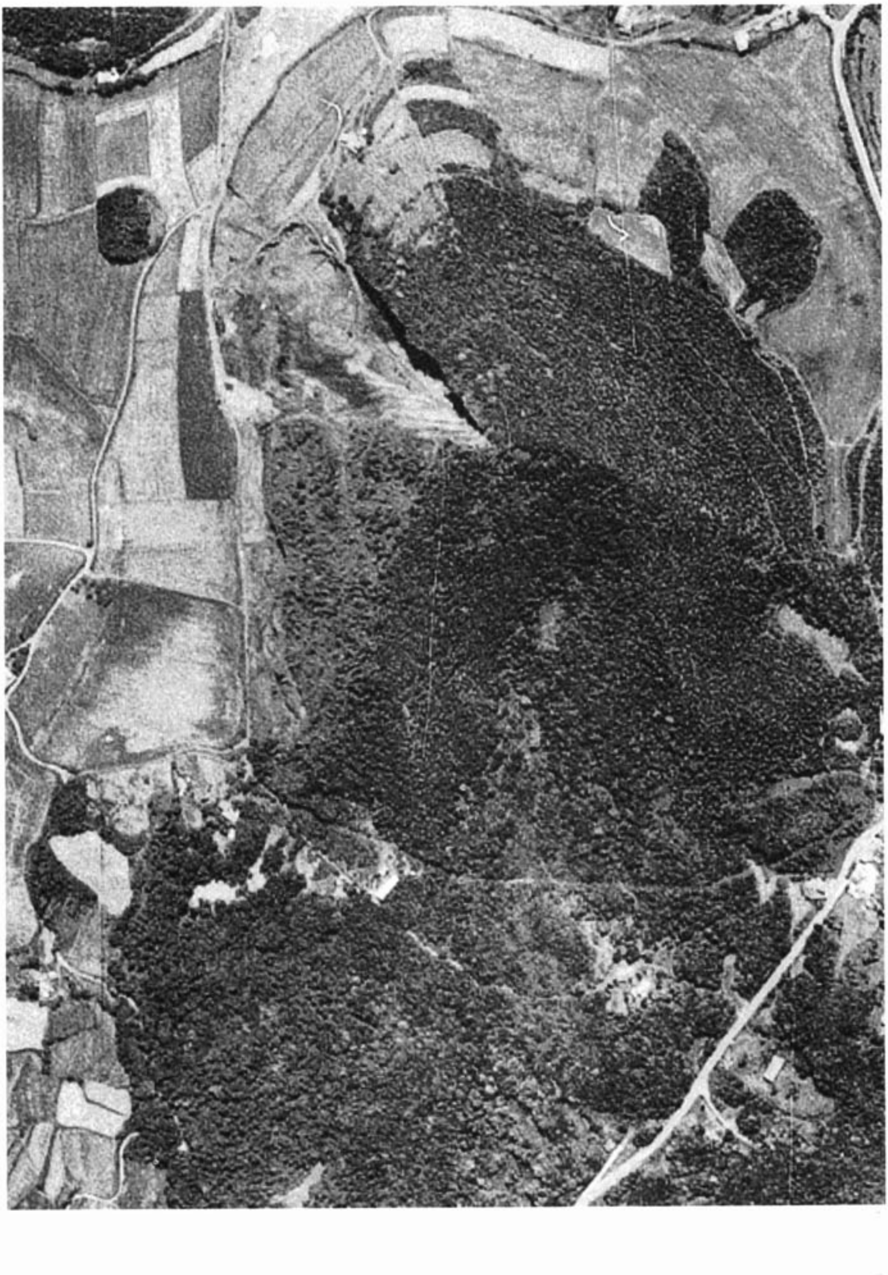

Figura 3: *Semiphotointerpreted orthoimage (UTM-31N: 460742 4666659 and 462342 4667859). In red: sharp boundary. In blue: fuzzy boundary.*

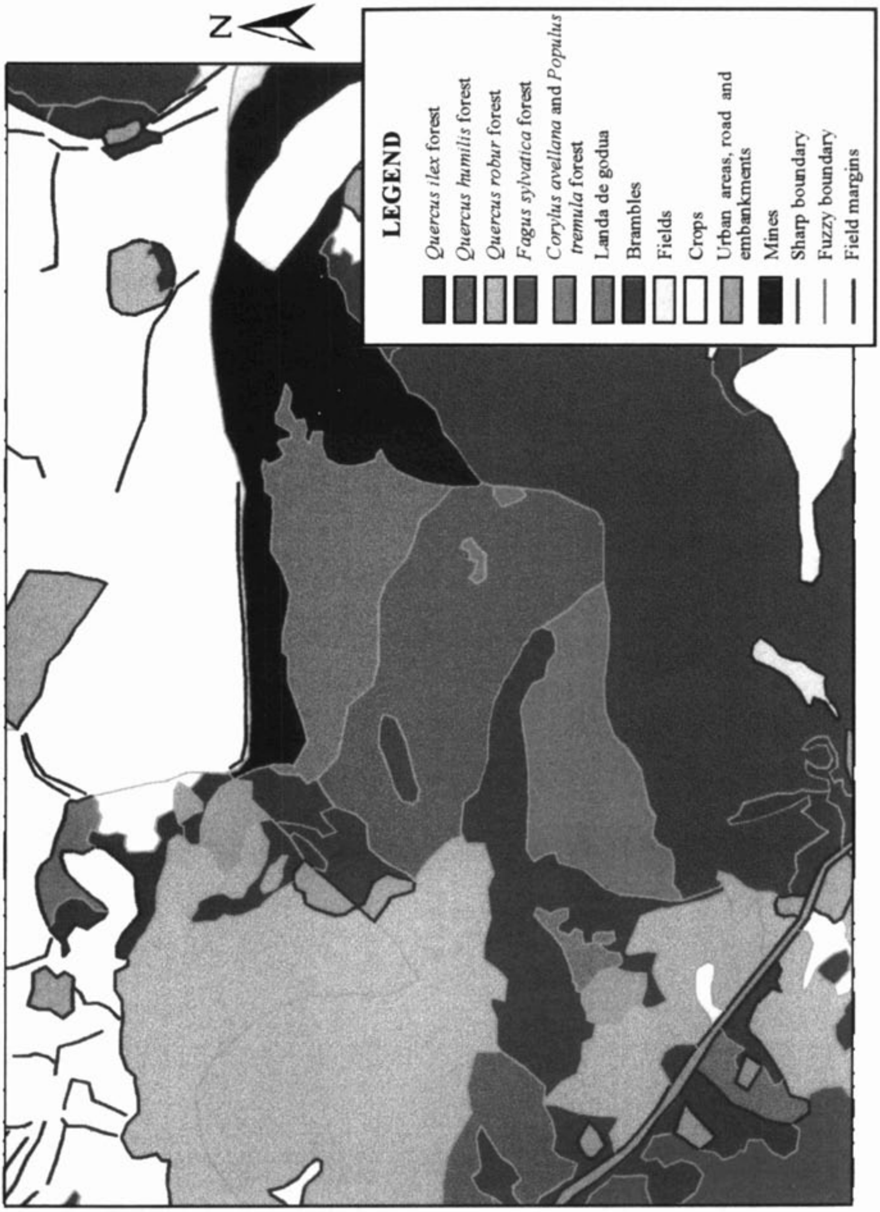

Figura 3. *Fragment of the vegetation map of the Garrotxa Volcanic Zone Natural Park (UTM-31N: 460742 4666659 and 462342 4667859).*

(1081 ha) orthophotomap varied from 4 to 7 hours (that is, from 270 ha/hour to 154 ha/hour) according to complexity. This cannot be considered excessive given that the working scale is detailed and involves delimitation of polygons not mapped in classical cartography. Obviously, this time can be reduced if a simpler legend is required or less planimetric precision is needed, or if the final printed map is on a smaller scale (for example 1:50000), which implies less detail in the thematic contents of the map.

The 1:25000 colour orthophotomaps of the ICC, of 2.5 m resolution, are of great utility in vegetation mapping given that the scale, quality and colour are ideal for vegetation interpretation. It is unfortunate that the same product in colour infrared (IRC) was not yet available, as this would further aid discrimination of the vegetation formations. If IRC colour images do not exist to complement the orthoimages, B/W photographs can be useful if they add detail (larger scale) or more recent information.

The time necessary for field validation oscillated between 1.5 and 2 days, depending on the orographic and vegetation complexity (that is from 90 ha/hour to 68 ha/hour). Few photointerpretation errors were found in the field, which indicates that photointerpretation from the colour orthophotographs is good. The time taken to correct errors and to assign definitive attributes, oscillated between 2 and 4 hours per A3 sheet (that is from 540 ha/hour to 270 ha/hour) depending on the complexity of the area; this is considered acceptable. The time total including all phases (photointerpretation, field work and error correction) was between 60 ha/hour and 40 ha/hour.

Once complete, the map is transferred to a raster or vector structure to detect any further errors (CAMPOS et al., 1995). During this phase the most important problem is file size. It should be noted that the number of errors located during these processes was low and will depend directly on operator concentration. The correction time is insignificant with respect to the total work volume.

The final map is a digital product and can be printed at different scales unless saturation of information occurs (at small scales generalisation is needed) or the original planimetric precision is affected. For the latter, we suggest a maximum scale of 1:6000, in accordance with the recommendations and planimetric and thematic considerations detailed in ROSSO (1979), FISCHER (1991), MERCHANT (1987), ARONOFF (1989) and PONS (1992). Figura 4 shows a fragment of the map printed at a scale of 1:10000.

Considering the legend, 108 units were observed, grouped into 14 principal categories. Of the total, 25 % are pure units and 75% are complexes. The elevated number of categories reflects the high resolution at which the map was elaborated and which allows fine definition of the vegetation groups.

In conclusion, it is clear that digital cartography tools allow more precise photointerpretation and a rapid correction of errors that, overall, give very satisfactory results for vegetation mapping. Furthermore, this type of digitally elaborated product has the advantage of being easily created, reproduced, corrected and updated using techniques similar to those used in the elaboration, while being very low cost. We believe that both the protocol and the vegetation map produced (the first in Catalonia and probably in Spain using a similar technique) will be useful, as a methodological tool and as a product for query and analysis, to those people interested in vegetation cartography.

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