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4 authors, including:

Isabel Castro
Universidad Autónoma de Madrid

Juan Carlos Moreno Saiz
Universidad Autónoma de Madrid

Paul Hugh Williams
Natural History Museum, London

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STRENGTHENING THE NATIONAL AND NATURAL PARK SYSTEM OF IBERIA TO CONSERVE PTERIDOPHYTES

JUAN CARLOS MORENO SAIZ[1], ISABEL CASTRO PARGA[2], CHRISTOPHER J. HUMPHRIES[3] AND PAUL H. WILLIAMS[3]

Facultad de Ciencias, [1]Departamento de Biología y [2]Departamento de Ecología, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, España
[3]The Biogeography and Conservation Laboratory, The Natural History Museum, Cromwell Road, London SW7 5BD, U.K.

Abstract

The diversity of the Iberian pteridophyte flora has been investigated using WORLDMAP v. 3.09 and 3.19. Two data sets scoring plant distributions as presences within the Iberian Peninsula were compiled; one for 128 species on 50 × 50 km grid and the other for 83 species on 10 × 10 km map grid cells. Patterns of biodiversity were determined using the diversity measures of species richness, range-size rarity and character richness diversity and character combinations. Using the diversity measures, combined with an area selection method, maps of priority areas were calculated using iterative procedures. Near minimum sets (NMSs) for both scales were calculated. Comparison of the NMS for the 10 × 10 km grid with the near minimum set for existing reserves (NMSER) showed that the protected area network, currently comprising 6% of the area, was insufficient to ensure representation of all species at least once as listed within the present data-base. Increasing representation of each species up to ten occurences within NMS networks showed that a smaller but more dispersed reserve system was a more desirable arrangement for conserving pteridophytes.

Introduction

The Iberian pteridophyte flora is the confluence of the Euro-Siberian flora (predominant in the Cantabrian and Pyrenean mountain ranges, and the north and northwest Peninsula on the Atlantic side) and the diverse Mediterranean flora which fills the rest of the Peninsula and the Balearic Islands. One explanation for the richness of the southern area is that it was a refuge area that remained virtually free of ice during the Quaternary glaciations (Lautensach, 1967). The relatively small thermal fluctuations and oscillations of rainfall and humidity created suitable environments of great diversity that still remain (González Bernáldez, 1992).

Development of biodiversity measures has become a minor growth industry in recent years (see Humphries *et al.*, 1995) and has emerged largely out of the realisation that not all areas are available for conservation, and efforts need to be concentrated in choosing priority areas to conserve biodiversity. From the various prescriptions that have been presented over the last few years we can make some generalisations about the basic principles for selecting a representative reserve system. The issue involves how we measure biodiversity, how we might locate it and how we determine the minimum requirements of reserve selection to determine a representative system in relation to a particular goal (Rebelo and Siegfried, 1990). The questions discussed in this paper are based on a study of the Iberian pteridophyte flora and how well the protected area system in Spain and Portugal contributes to its safeguard.

One of the consequences of the *Convention on Biological Diversity* (see Glowka *et al.*, 1994) is that there is a need to develop national and regional plans which have protected area systems capable of preserving and maintaining biodiversity within existing political units. In this example, we wish to show to what extent the existing reserve system is capable of representing the pteridophyte flora of the Iberian Peninsula and the Balearic Islands. Future studies will need to examine the conservation priorities of Spain and Portugal as separate national surveys. We describe various ways of measuring biodiversity, and provide a method for calculating representative systems.

The Iberian Peninsula is one of the richest areas surrounding the Mediterranean Sea with a flora of about 7000 taxa (species and subspecies) of vascular plants (Castroviejo *et al.*, 1986; Castro Parga *et al.*, in press). As measured on the 10 × 10 km grid map, the protected area system in Spain and Portugal (excluding Macaronesia) occupies 415 square kilometres representing something like 6.5% of the total land surface. The park system of the Iberian Peninsula is divided into two categories, National and Natural Parks, representing 0.7% and 5.7% respectively, in a total land surface area of approximately 6330 square kilometres south of the Spanish border with France, including Andorra (Castro-Henriques, 1988; Ruiz de Larramendi *et al.*, 1992).

For the purpose of this study we compiled two data sets from all available plant maps that we had either produced ourselves or which had appeared in the literature over the last twenty years or so.

Materials and methods

With the purpose of investigating pteridophyte diversity using different map scales, our initial step was to compile all species distribution maps available for the Iberian Peninsula. These were converted from existing maps, wherever possible, onto a 50 × 50 km grid and a 10 × 10 km grid, i.e. as new maps in WORLDMAP (Williams, 1994) (Figs 1–6). Both grids are modified UTM grids to take advantage of records that have been compiled previously within that format. The 50 × 50 km grid was based on *Atlas Florae Europeae* (Jalas and Suominen, 1972). To compensate for the Earth's curvature there is a gradual loss of squares on both sides of the 'huso' zones. The same feature was established on the 10 × 10 km grid, which meant that some of the cells are not equal areas. Thus, the Peninsula is depicted in a rather deformed manner (e.g. Figs 5, 6).

The distribution data is our own compilation from different bibliographic sources, including all available published and unpublished records known to us. For the 50 × 50 km grid the principal sources included the previously published atlases of Jalas and Suominen (1972), Salvo *et al.* (1984), together with a variety of generic revisions and separate map publications. For the 10 × 10 km data base, the more recent chorological syntheses of Bolòs and Romo (1991) and Bolòs *et al.* (1993) were utilised together with a number of publications from within journals. Finally, 128 distribution maps (species and subspecies, Figs 5, 6) were compiled for the 50 × 50 km grid and 83 maps for the 10 × 10 km grid (Figs 1–4).

The data sets were analysed using the WORLDMAP software for personal computers (Williams, 1994). This provides a simple graphical database and a range of measures relating to different calculations of diversity value. Four basic options were used in this analysis (A–C below). To calculate an optimal system of reserves from our data, and to assess the efficiency

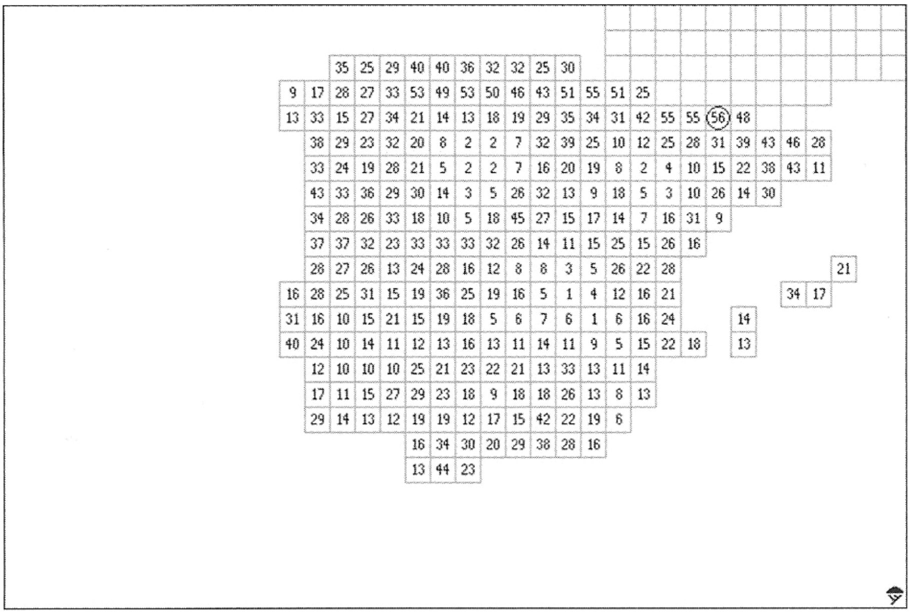

FIG. 1. Map of species richness from all available published map data for 128 species of pteridophytes among 50 × 50 km grid cells for Iberia. The map was based on the UTM grid of Jalas and Suominen. (1972–1991).

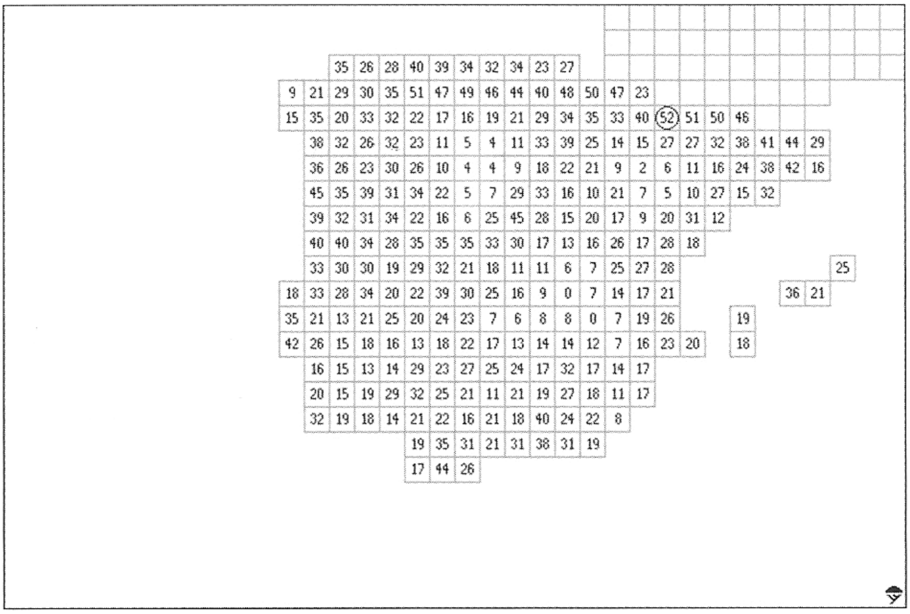

FIG. 2. Map of percentage character richness scores for 128 species of pteridophytes among 50 × 50 km grid cells of the Iberian grid derived from the standard UTM map.

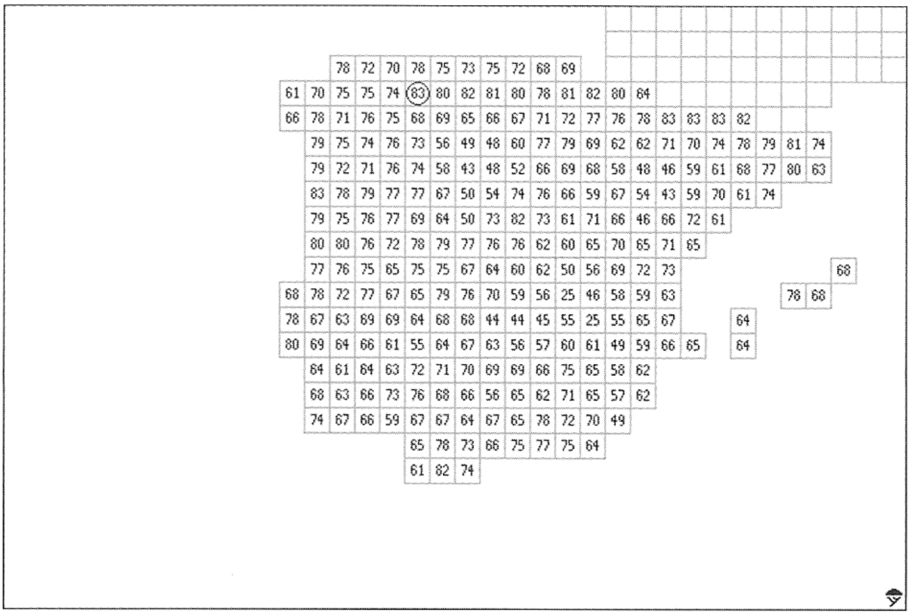

FIG. 3. Map of percentage character combination scores for 128 species of terrestrial vascular plants among 50 × 50 km grid cells of the Iberian grid derived from the standard UTM map.

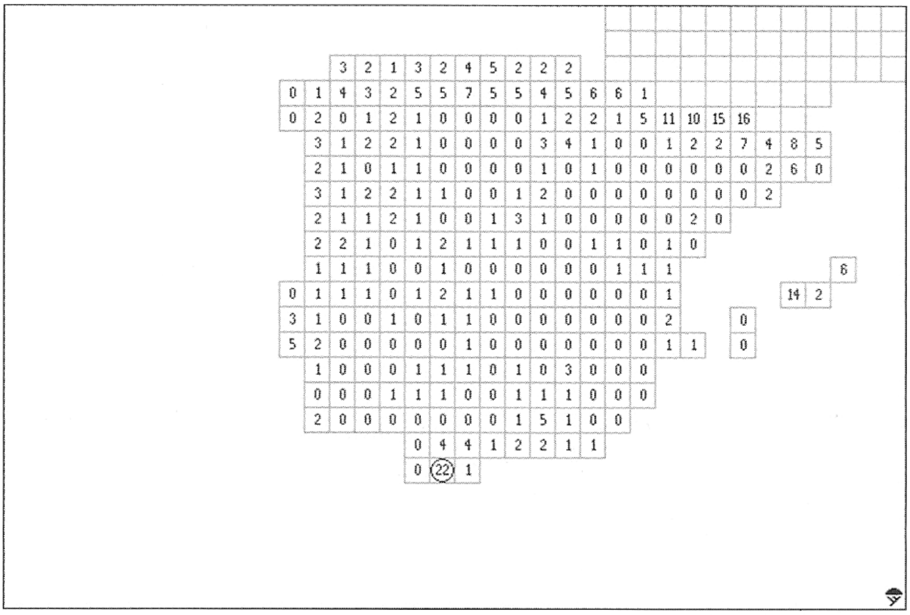

FIG. 4. Map of percentage range-size rarity scores for 128 species of pteridophytes among 50 × 50 km grid cells of the Iberian grid derived from the standard UTM map.

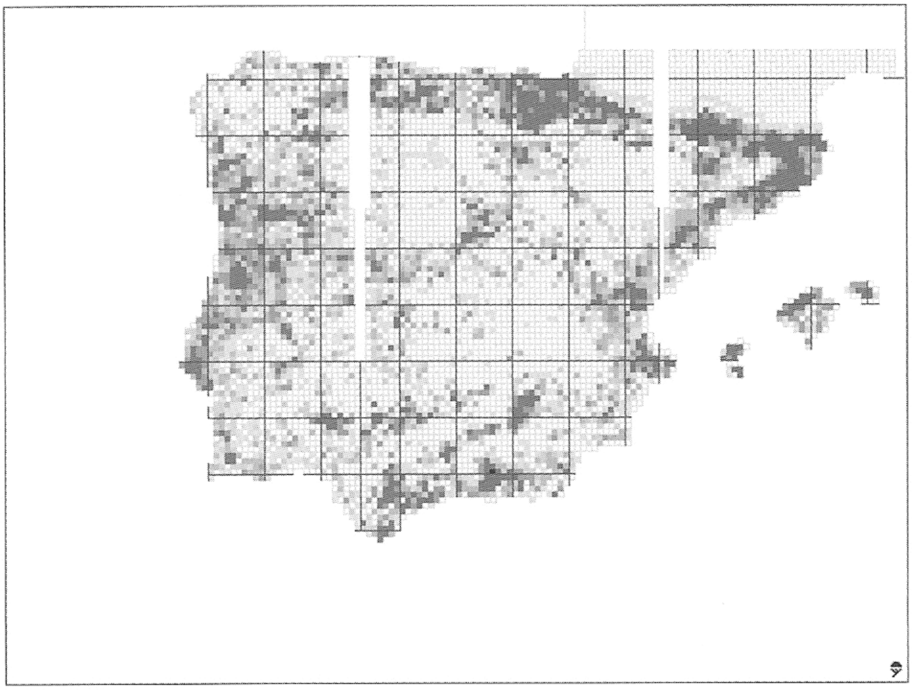

FIG. 5. Map of species richness scores species as a predictor of the 83 species scored for the 10 × 10 km grid cells of the Iberian grid derived from the standard UTM map.

of the existing reserve network, the heuristic method described by Williams (1994) for calculating NMSs, incorporating the principle of complementarity and the technique of priority areas analysis (D and E below), was used.

A. Species richness (Figs 1, 5)

This is a simple count of the number of species recorded in a grid cell. The species complement of an area is still justified as one of the most easily accessible of the biodiversity measures (Williams, 1994).

B. Range-size rarity (Figs 4, 6)

Range-size rarity is a measure which reflects geographical range size (Rabinowitz, 1981). WORLDMAP provides a continuous measure of range-size rarity, which is calculated as the sum of inverse frequency of occupancy among all grid cells for all species occurring in the grid cells (Usher, 1986; Howard, 1991; Williams, 1993). In this study, range-size is measured only within the Iberian Peninsula and the Balearic Islands (Williams, 1994).

C. Character richness (Fig. 2)

One interpretation of a currency for biodiversity is character richness among species. Character richness for sets of species can be estimated in a variety of ways. For our analyses

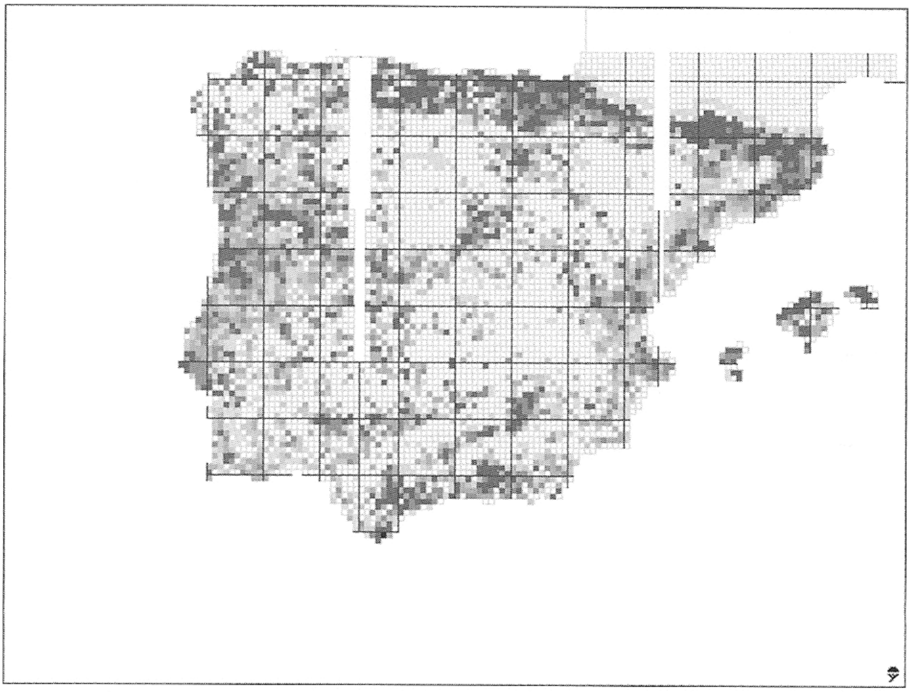

FIG. 6. Map of range-size rarity scores for 83 species of pteridophytes among 10 × 10 km grid cells of the Iberian grid derived from the standard UTM map.

of character richness, we used a classification of land plants (Bremer, 1985), an underlying node-counting model reflecting regular changes in character evolution in the classification, and a spanning subtree measure (Williams, 1996; Humphries *et al.*, in prep.; Williams *et al.*, 1994). Spanning subtrees sample areas which have the maximum character richness relative to other areas. Thus an area containing a lycopod, a species of *Asplenium* and an angiosperm would possess greater character richness than an area containing three closely related species of *Asplenium*. Character richness creates a value for the numbers of taxa per grid cell weighted by the spanning-subtree count, to be plotted on the grid as a percentage of the total tree count score for all of the taxa in a group (Williams, 1994).

D. Richness in character combinations (Fig. 2)

An alternative interpretation of a currency of biodiversity is the richness of different combinations of species characters. Richness of character combinations among species can then be maximised using taxonomy, models relating evolution to classification and dispersion (regularity and evenness) measures (see Williams *et al.*, 1994; Williams, 1994). We used a discrete p-median measure to determine regularity as implemented into WORLDMAP versions 3.09 and 3.19.

E. Complementarity

For ecologists and conservationists alike, the partial turnover in taxa between areas or sites, is critical for assessing biodiversity (Whittaker, 1960; Magurran, 1988). This is necessary as areas of similar species density or richness can have quite different complements, thus taxic identity is crucial. Vane-Wright *et al.* (1991) coined the term complementarity for the concept that one area or site contains a portion of the biodiversity not represented in other areas with which it is being compared. Several methods have been developed that capture the maximum biodiversity in the minimum number of sites or areas. Complementarity is central to many methods including site selection methods of Kirkpatrick (1983) (see also Colwell and Coddington, 1994), *Critical faunas analysis* (Ackery and Vane-Wright, 1984; Collins and Morris, 1985), minimum step iterative methods of Margules *et al.* (1988) and Rebelo and Siegfried (1990) and minimum set methods (Possingham *et al.*, 1993). Using complementarity of biotas between areas provides the possibility of determining the smallest set of areas that will represent all species once (or any given number of times for different levels of representation). As a basis for selecting a network of sites, this is more efficient than the hotspot approaches (Prendergast *et al.*, 1993; Curnutt *et al.*, 1994; but see also Williams *et al.*, 1996).

F. Priority areas analysis

Reserve selection methods in WORLDMAP are of two kinds; step-wise procedures based on greedy algorithms that maximise complementarity at each step, and set-wise procedures that endeavour to obtain minimum sets. Using set-wise procedures the goal of representation can be set, prior to analysis, and then calculated for the attributes within the database (species, higher taxa etc.). For set-wise and step-wise procedures WORLDMAP can be used to determine ordered sequences of priority areas by maximising the complementarity criterion for species richness, endemism, character richness and character combinations at each step. This can be undertaken interactively so that area choices can be controlled at each step to account for external factors, or automatically using the minimum set option. For automated sequencing, WORLDMAP version 3.19 uses an heuristic procedure for searching for the shortest sequences of areas, which are then ranked according to a particular measure of biodiversity, i.e. species richness, character richness, character combination richness and range-size rarity in this study. The procedure consists of three passes over the data (see Appendices 1 and 2). The first pass selects a sequence of grid cells to maximise the complementarity endemism score at each step (selecting preferentially for grid cells with narrowly distributed taxa to find a short, if not minimum, sequence of areas). Ties are broken with the range-size rarity score without complementarity. The second pass checks back through the selected grid cells to find any that lack unique species within this set in order to eliminate redundant grid cell choices. The third pass re-orders the retained grid cells to maximise the chosen diversity or rarity measure at each step. Tied scores are broken using the total species richness for the grid cell, without complementarity.

The purpose of area-selection algorithms is to optimise biodiversity for a particular set of areas, when the choice of areas is limited. Area selection methods can be applied to determine the efficiency of existing protected area systems, and to calculate additional areas required to add to the system to satisfy a particular goal of representation. To calculate efficiency, the areas of an existing reserve system are compared to an ideal system. The ideal NMS is calculated and then compared with the area or number of areas in the existing reserve system together with additional areas to satisfy the goal of representation. This is the NMSER for the National and Natural Park system combined. The NMSER is calculated by retaining the squares required for the existing park network and then re-running the minimum set algorithm to add the missing areas of the residual complement to the existing reserve complement (ER) already captured. The efficiencies of the two existing systems were calculated by comparing the

NMSER with the minimum set (MS). There are a variety of different measures for calculating efficiency (E) (see Pressey *et al.*, 1993) but the measure used here is taken from Humphries *et al.* (in prep.) and uses the following formula:

E = (ER - NMSER + MS) / NMSER

Results

A. Species complements (50 × 50 km grid)

The species richness scores for the 128 taxa is mapped in Figure 1, where each cell is the sum of the individual species distributions. In Figure 1 higher scoring grid cells occur in the principal montane regions of Iberia. The 50 × 50 km grid shows the highest scoring area is in the Western Iberia with high concentrations in the mountains of the Cantabrian Range of the northern Sistema Ibérico, the central montane system and the Baetic ranges, and generally towards the western half of the Peninsula. The coldspots (areas of low richness; Prendergast *et al.*, 1993) are around the river basins of the south and in the endorheic basins from the north and east of the Peninsula. Character richness scores are mapped in Figure 2, which shows that the areas with greatest character diversity are comparable to species richness. Character combination scores show a similar pattern (Fig. 3) but indicate that squares with low species richness have diverse complements of pteridophytes. Range-size rarity scores indicate a pattern comparable to species richness but emphasise the sandstone areas in southern Spain and the Balearic Islands (Fig. 4). The range size rarity measure clearly highlights Sierra Nevada as providing the richest complement, but other important areas include some Pyrenean squares and western Majorca (Mallorca). The other critical complements are found in the western Cantabrian mountains and the Central system.

B. Species complements (10 × 10 km grid)

Although there are many empty grid cells in the 10 × 10 km map of 3555 recorded cells from a total of 6831, the finer scale shows very similar patterns of species richness and endemism to the 50 × 50 km map (Figs 1, 2, 5, 6). The hot spots with all four measures are Sierra Nevada (species richness), Setubal (character richness), Albergaria (character combinations) and Sierra de Algeciras (range size rarity). The same predominant mountain ranges are selected within the top ten sites but with varying combinations of actual squares and sequences. This is due to the fact that although comparable areas are essential to determine the full complement, there are many combinations of flexible areas that can contribute to reaching this goal.

C. The National and Natural park system - near minimum sets (NMS)

Analysis of 128 species on the 50 × 50 km grid system requires a NMS of 19 areas to represent every taxon at least once (Fig. 7; Appendix 1). From the minimum set of 20 cells amongst the 10 × 10 km grid, it is possible to analyse the effectiveness of the NMSER for the National and Natural park system combined (Fig. 8). The existing National and Natural park system is shown in Figure 9 and occupies 415 10 × 10 km grid cells. It occupies approximately 6% of the Iberian land surface in terms of 10 × 10 km cells. The NMSER for the entire parks system requires 427 10 × 10 km grid cells (Fig. 10).

The near minimum set of 10 × 10 km grid cells for the sample of 83 species (Fig. 8, Appendix 2) is taken to have an efficiency value of 1. By contrast, the efficiencies of the existing reserve systems are determined by calculating how many extra 10 × 10 km grid cells are required beyond those already within the reserve system to obtain full representation of the

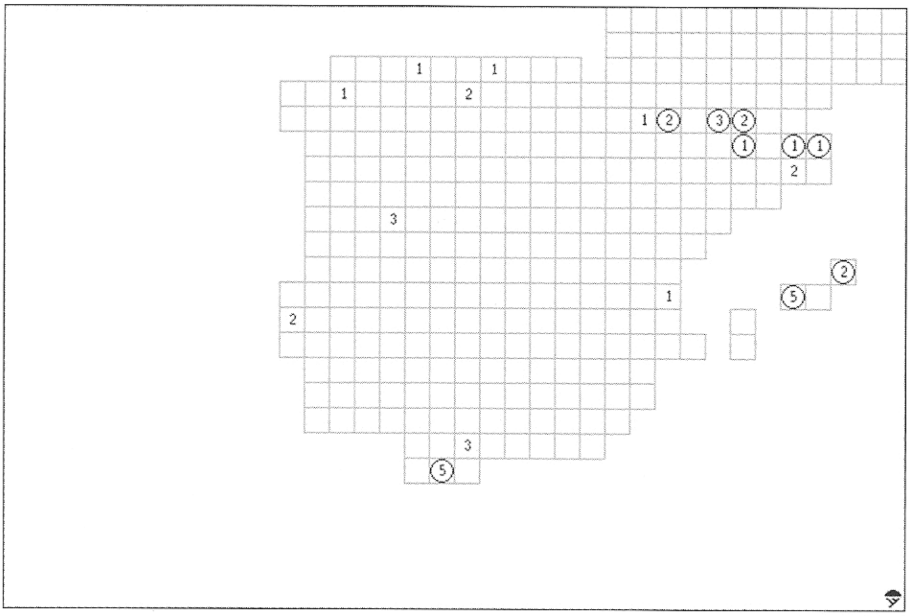

FIG. 7. Map of near minimum set for 128 species of pteridophytes among 10 × 10 km grid cells of the Iberian grid derived from the standard UTM map. Circled scores show irreplaceable grid cells and scores in open squares show flexible squares.

floristic sample. The National Park and Natural Park system is currently represented in 415 squares and 427 are required to determine the existing reserve minimum set with at least one representation of each species. Consequently, 12 extra squares are required which is equivalent to saying that, of the existing 427 squares, only the equivalent of eight squares are making a contribution to overall representation, because of redundancy in the other squares occupied by the park system. The efficiency of the existing reserve minimum set for the national parks is thus approximately 0.02.

The near minimum set of Figure 8 is for at least one representation of each taxon. It can be seen that increasing representation is more or less a linear progression (Fig. 11). The NMS for ten representations is given in Figure 12. Increasing the level of representation in the NMS network shows that smaller, more dispersed, reserve systems are desirable for conserving pteridophytes in the Iberian Peninsula.

Discussion

In terms of species richness the patterns of Iberian-Balearic pteridophyte diversity coincide with overall species richness patterns of land plants (Castro Parga *et al.*, in press). Independent of scale and different options within WORLDMAP, the Peninsula mountain ranges harbour greatest diversity and the coldspots occur in the inner lowland areas. From an historical point of view the mosaic aspect of the pattern has to be analysed within a Mediterranean context against a background of over a millenium of varied agricultural, silvicultural and pastoral

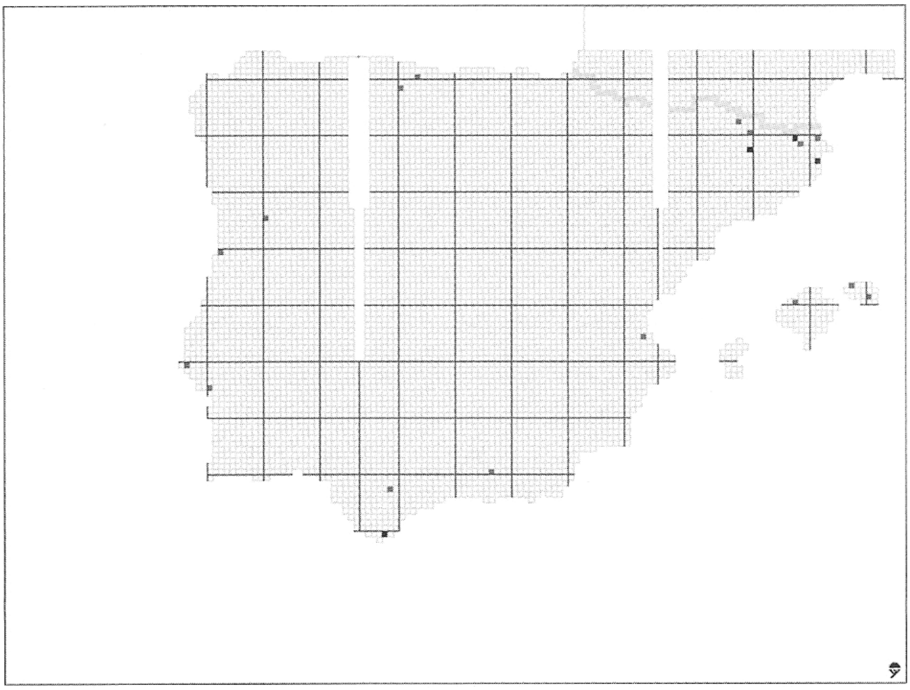

FIG. 8. Map of near minimum set (20 squares) for 83 species of pteridophytes among the 10 × 10 km grid cells of the Iberian grid derived from the standard UTM map.

practice. It is difficult to be precise, but the mountains are perhaps the most undisturbed habitats as compared with the lowlands which have been subjected to so much continual intensive use by humans. A compounding effect has been the lack of adequate catalogues and floristic research especially within the lowland areas (Moreno Saiz and Sainz Ollero, 1989).

In the Mediterranean areas of the Peninsula, Sierra Nevada and the rest of the Baetic ranges are the most diverse, with also the highest numbers of Iberian endemic species. Alpine folding, tectonic movement and erosion have created areas of complex geology with steep, sculptured relief, and periods of seasonal and unpredictable drought have allowed for an intensely varied flora. Plant communities are sharply defined and are very different from each other, quite unlike the smoother gradients so characteristic of northern European habitats (González Bernáldez, 1992). The areas of Iberian endemics are small, and frequently confined to one habitat on one particular mountain. It was unsurprising therefore that during priority areas analysis at the 10 × 10 km scale, selection of one particular square did not cater for surrounding squares of similar geography and physiognomy. For similar reasons a disproportionate number of squares are required to represent the pteridophyte sample of the Baetic range and the Balearic islands.

Examining the sequences of areas required for 128 species on the 50 × 50 km grid provides a result more similar to the larger data set at that scale, rather than the finer 10 × 10 km scale. This supports the conclusions of Pressey and Logan (1995) that very different ideas can be drawn as a result of changing map scales. We consider that although the 50 × 50 km grid system is far too coarse for determining regional priority areas within the Iberian Peninsula the

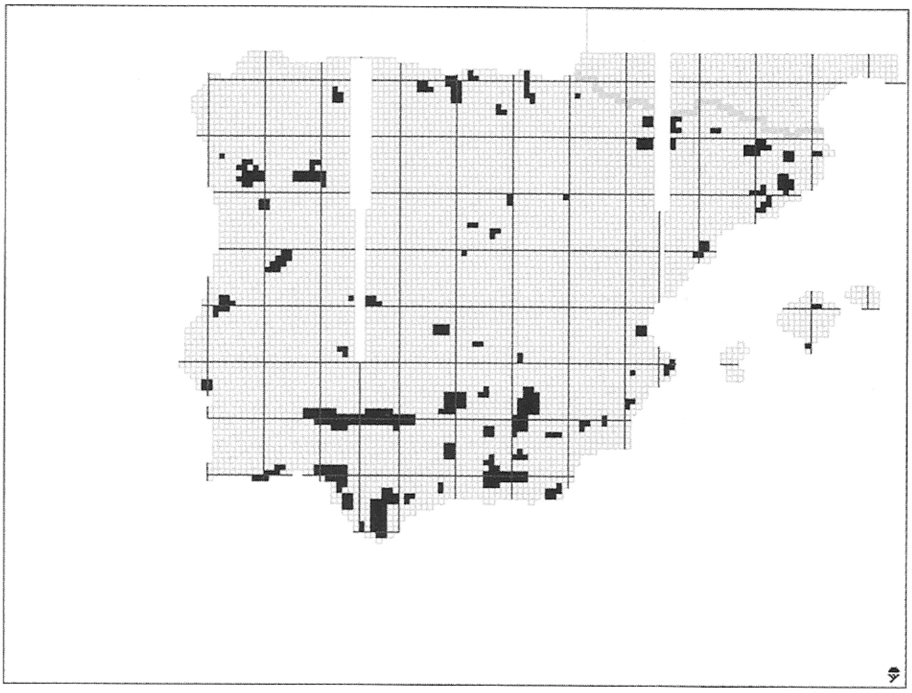

FIG. 9. Map of National and Natural park system in Iberia among the cells on a 10 × 10 km grid.

turnover pattern is apparent. The 10 × 10 km grid system appears to be sufficiently fine to provide a fairly useful guide to priority areas. As only 83 (about 1% of the vascular flora) species could be mapped at this scale it is impossible to provide a detailed analysis of all the truly species-rich areas and areas of high endemism (*sensu* Sainz Ollero, 1983; Gómez-Campo *et al.*, 1984; Hinz, 1990). However, comparing their results with ours does show considerable correspondence and the sample of 83 species is reflecting the richer pattern of 2133 species mapped by Castro Parga *et al.* (in press).

Conservation of biodiversity has only relatively recently emerged as an issue of concern (see Groombridge, 1992; UNEP, 1995). Conservation policies in the Iberian region have led to the creation of seven large territories with National Park status and about eight times as much area set aside for the Natural park system (Fig. 9). The criteria of choice for these parks has ranged from humid areas for bird nesting sites to the preservation of alpine landscapes, and like so many other places on the globe are less than optimal when different goals are in mind such as conserving biodiversity.

There is a growing awareness within the international conservation movement that existing reserve networks can be greatly improved to enhance their effectiveness in conserving biodiversity, especially for groups of sectoral interest such as pteridophytes. Calculating efficiency by comparing the optimal set with the existing reserve minimum set goes a long way towards setting the baseline for recognising further needs. The approach of setting a clear goal as to which areas are required to represent all plant species for which maps are available represents a start in what we hope will become a growing monitoring exercise. The minimum

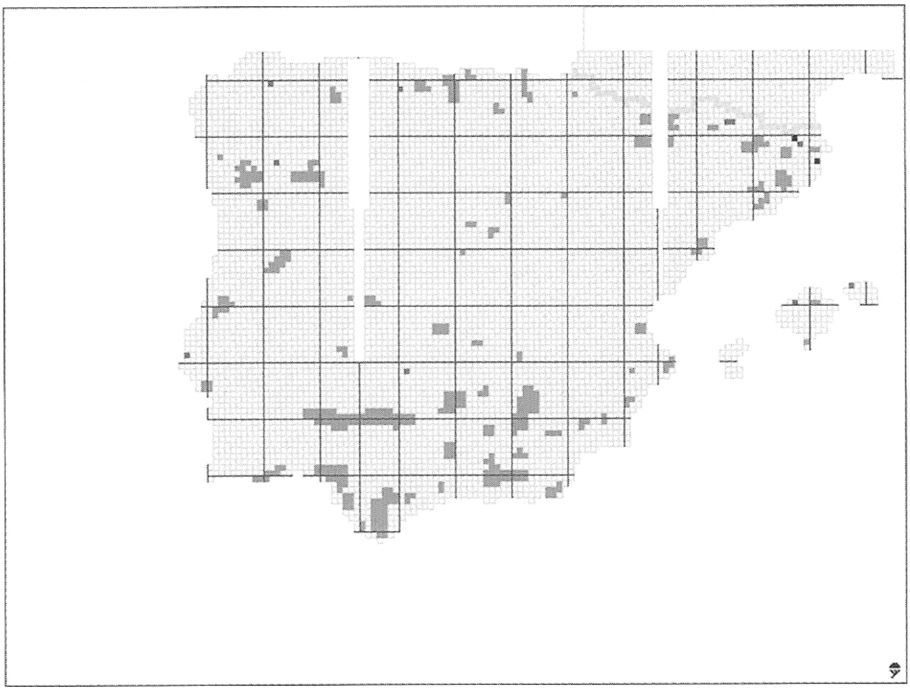

FIG. 10. Map of existing reserve minimum set for the National and Natural park system calculated from 83 species of pteridophytes on a 10 × 10 km grid.

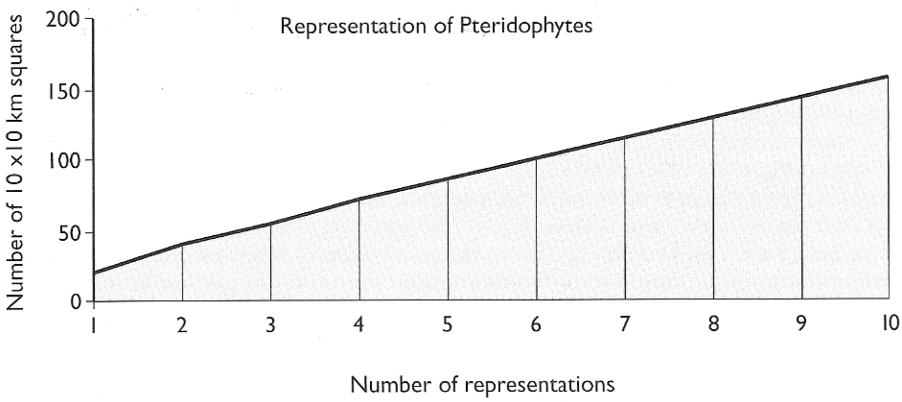

FIG. 11. Number of sites required for 1–10 levels of representation of pteridophytes in the Iberian peninsula.

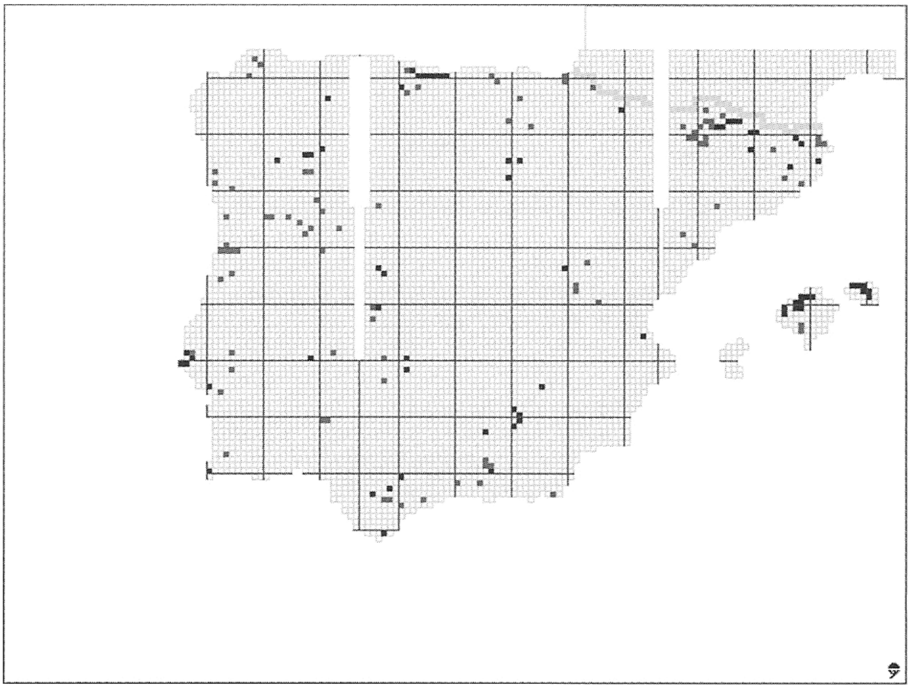

FIG. 12. Map of near minimum set of 83 species of terrestrial vascular plants on 10 × 10 km grid cells with a goal of four representations on the Iberian grid.

(or near minimal) set should not be seen as an unyielding prescription for nature reserve design but more of a logical defence for selection of areas in relation to the fulfilment of a particular goal such as representation of all species in at least one viable population. A minimum set should never be confused with the required reserve network, but rather the minimum set should be seen as a valuable tool that calculates the bottom line of required areas to satisfy any given goal of representation. Ideally, we would like to have data on the entire flora and fauna with multiple representation of viable populations as our conservation goal, but such an option is for future concern. As a final comment we strongly recommend that the pteridophyte community who monitor conservation (i.e. SSC/IAP SG) should explore these approaches and see if any of those sites lacking protection can be incorporated into the protected area system.

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