GIS ANALYSIS OF THE FRAGMENTATION OF FORESTS IN A NATIONAL PARK: ASSESSMENT AND RESTORATION[1]

A. GKARAVELI[2,3]

ABSTRACT

The purpose of this study was to examine the landscape characteristics of the forests and woodlands in the Snowdonia National Park, North Wales (UK). Using a geographical information system, several landscape indices were calculated for the broadleaves, conifers, mixed high forest and scrub vegetation categories. All woodland fragments were analysed in terms of their area, density, degree of isolation and shape in order to understand their spatial distribution and connectivity. The analyses showed that the broadleaved habitat is dissected into a great number of patches, irregular in shape and with a mean patch size of <4 ha. Fragments of mixed forest had similar sizes and were more isolated across the landscape. Scrub contained many small and similar-sized patches, more regular in shape. When these habitats were analysed using an edge width of 100m, about 99% of the total scrub area was found to lie within edge habitat. Conifer forest presented as a very clumped habitat containing larger patches with higher variability in size. Objective GIS simulation techniques for ameliorating this fragmentation of the broadleaves, mixed forest and scrub were demonstrated using two sites in the Park. Simulations using these techniques show that i) conversion of conifers to broadleaves, ii) reforestation of agricultural land between woodland fragments or iii) creating buffer zones around existing woodland would considerably increase the area of interior or core habitat and connectivity between the presently fragmented native woodland. The study could provide the basis for informing policy and management aimed at enhancing native woodland cover and quality in the Park and elsewhere.

INTRODUCTION

The Snowdonia National Park in north Wales, was established in 1951 and is the second largest of the ten National Parks of England and Wales (FIGURE 1). Land ownership is predominantly private and traditional farming still remains the most widespread industry of the area. About 15% of the land is wooded and consists of broadleaves, conifers, mixed forest and scrub. Conifer plantations, which have often been established on unwooded land, cover nearly 70% of the wooded area and dominate the upland tree cover in the Park, as in many other parts of upland Britain. However, deciduous woodland once formed the natural cover for large parts of upland Britain, including Snowdonia (Linnard, 2000), with the majority of flora and fauna being woodland species (Atherden, 1992).

The Habitat and Species Directive (Council of the European Communities, 1992) refers to the need to promote the conservation of hedges, walls and other features (such as small woods) that might act as 'stepping stones' or 'corridors' to promote species movement through the countryside. This approach has been taken forward in Wales through the development of plans for a forest habitat network including core woodland areas (Anon, 1998). In addition, Tir Gofal, a new all-Wales agri-environment scheme, recognises the need to create and enhance natural habitats on farms wherever possible. A number of prescriptions are proposed including the planting of new woodland and the creation of wildlife corridors along streams and rivers (CCW/FC Wales, 1999)

1:ΑΝΑΛΥΣΗ ΜΕ Γ.Σ.Π. ΤΟΥ ΚΑΤΑΚΕΡΜΑΤΙΣΜΟΥ ΤΩΝ ΔΑΣΩΝ ΣΕ ΕΝΑΝ ΕΘΝΙΚΟ ΔΡΥΜΟ: ΕΚΤΙΜΗΣΗ ΚΑΙ ΑΠΟΚΑΤΑΣΤΑΣΗ

2:School of Agricultural and Forest Sciences, University of Wales, Bangor, Gwynedd, LL57 2UW, Wales, U.K. Tel. ++44(0)1248 382281; Fax. ++44(0)1248 354997; E-mail: afp427@bangor.ac.uk

3:Forest Authority of Prefecture Magnesia, Xenofontos 1, 38333, Volos, Greece. Tel. +30(0)4210 39109; Fax. ++30(0)4210 39107; E-mail: anthi_gkaraveli@hotmail.com

When applying any of these guidelines to woodland conservation planning in the National Park, it is important to assess the landscape characteristics of the Snowdonian woodland types in order to understand their present conservation status. Conservation efforts must focus on the forest fragments that are present in Snowdonia and more information is needed for their management. In this study we aim to increase this understanding by analysing, using GIS and FRAGSTATS, all the forest fragments in terms of their area, density, degree of isolation and shape in order to understand their spatial distribution and connectivity, and inform policy and management aimed at enhancing native woodland cover and quality.

METHODS

The land use map of Snowdonia was derived from aerial photography and field survey by Silsoe College in the 1980s on behalf of the Countryside Commission and the National Park Authorities (Taylor, 1991). The map was of 1480 columns x 2192 rows with a 40m pixel resolution, included 38 categories of land cover and was manipulated using the IDRISI for Windows v.2.0. geographical information system (GIS) (Eastman, 1997).

The spatial analysis programme FRAGSTATS v.2.0 (McGarigal and Marks, 1994) was used to quantify the areal extent and spatial distribution of each forest patch type within the landscape of the Park. The programme calculated a set of pattern metrics for broadleaved, coniferous, mixed forest and scrub cover classes. The ereal extent of each woodland type was quantified by computing the class area (CA), the percentage area (PC) and number of patches (NP). The patch size distribution was assessed by computing the mean patch size (MPS) and patch size standard deviation (PSSD). The mean shape index (MSI) (average perimeter-to-area ratio measured against a square standard) was used to assess changes in the complexity of patch shapes. MSI equals 1 when all patches are square and increases when patches become more irregular. Patch isolation was quantified with the mean nearest-neighbor distance (MNN) (average distance from a patch to the nearest neighboring patch of the same type, based on edge-to-edge distance) and patch dispersion with the nearest-neighbor standard deviation (NNSD). A small NNSD relative to the mean implies a fairly regular distribution of patches across the landscape (McGarigal and Marks, 1994).

Core area is defined as the area within a patch greater than some specified edge distance or buffer width (McGarigal and Marks, 1994). It is likely that 'edge effects' will vary in relation to the habitat concerned and species of interest (Dawson, 1994). There are no published targets for 'ideal' edge zone width for Snowdonia. In this work, as a result of insufficient empirical support for using specific edge distances, for the calculation of total core area a range of edge sizes was used (20, 50, 70, 100, 130 and 150m) and an attempt was made to explore their implications.

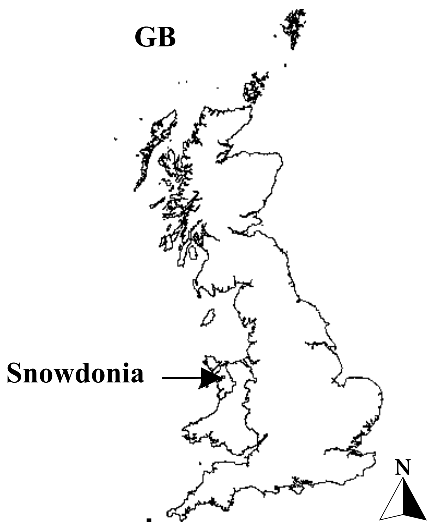

FIGURE 1. Location of the study area, Snowdonia National Park, Wales.

RESULTS

The landscape of the Snowdonia National Park varies in the amount and pattern of broadleaved, coniferous, mixed high forest and scrub habitat. Approximately 10% of the landscape is coniferous forest, in contrast to only 3.8% of broadleaved forest, 0.5% mixed forest and 0.6% of scrub (TABLE 1). The broadleaved habitat is dissected into a great number of patches with mean patch size less than 4ha. Although the overall areas of scrub and mixed forest are similar, scrub consists of many more smaller patches. Patch size standard deviation in scrub is several times smaller than in other classes, due to the many small and similar-sized patches. These reflect the origins of scrub, most of which probably developed by natural regeneration during the periods of agricultural depression when grazing intensity by domestic livestock (chiefly sheep) was considerably less than at present (Good *et al.*, 1990). Scrub is now maintained as a plagio-climax through intensive grazing. Mixed forest also contains some similar-sized patches, but the patches are much larger and there are fewer of them. In contrast, conifer forest seems to be more clumped containing larger patches with a high variability in size.

Because FRAGSTATS evaluates each patch shape in the landscape, using a square shape as the standard, the value of the shape metric is minimum for patches with a square shape and increases as patches become increasingly non-square. The mean shape index values for the classes are all greater than 1 (TABLE 1), indicating that the average patch shape in all four classes is non-square. Scrub patches are the least irregular in shape, whereas the patches of broadleaves are the most irregular in shape.

TABLE 1. Class area, number of patches, mean patch size and other spatial indices for each forest patch type in the Snowdonia National Park (see text for index acronyms).

Land use/cover category	CA (ha)	Proportion (%)	NP (#)	MPS (ha)	PSSD (ha)	MSI	MNN (m)	NNSD (m)
Broadleaved Forest	8244	3.81	2110	3.91	13.41	1.53	118.07	183.60
Coniferous Forest	21815	10.07	733	29.76	128.05	1.52	266.83	417.29
Mixed Forest	1229	0.57	251	4.90	10.79	1.51	710.05	1065.83
Scrub	1355	0.62	873	1.55	2.52	1.35	288.24	407.22
Non-forested land	184021	84.93						
Total	216664	100.00						

For the calculation of total core area metric six edge widths were used, for all the cover classes, to allow examination of the changes in each class. Total core area remains the same in all forest types when the edge distance increases from 20 to 50m but further increase results in a rapid decrease in core area for all the classes in the landscape, especially for broadleaves and scrub due to the small size and irregular shape of their patches (FIGURE 2). With an edge zone set to 100m, the indices indicates that although scrub habitat contains 873 patches encompassing a total of 1355ha, there is less than 7ha of core area. The habitat has no core area when the edge width is 150m; no point in scrub patches is greater than 150m from the patch perimeter. Scrub habitat has much less core area than mixed forest, in all edge sizes, despite them both having similar areas of habitat, suggesting a greater edge-to-interior ratio and a much more dissected configuration of scrub habitat.

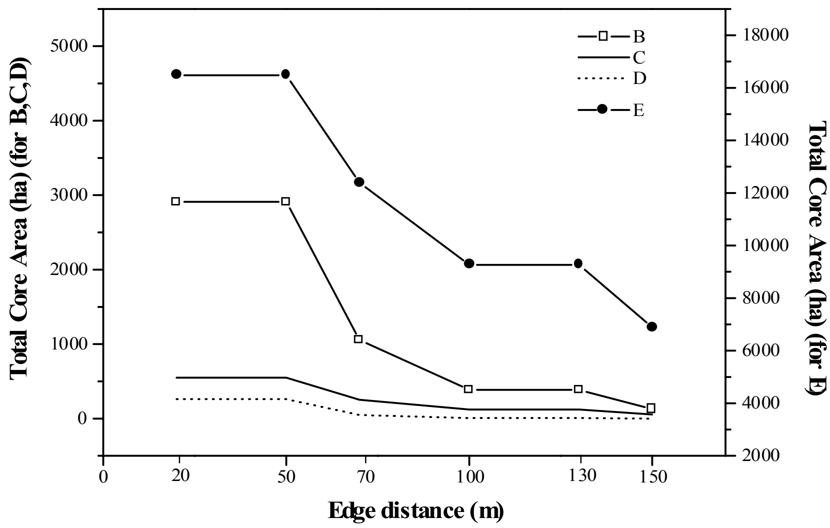

FIGURE 2. The total core area (ha) in each class as a function of the specified edge widths (m). B=broadleaved forest; C=mixed forest; D=scrub; E=coniferous forest.

Mean nearest-neighbour distance is greatest in mixed forest, probably influenced by the fact that there are many fewer mixed forest stands than other categories. These patches are very isolated in this landscape, whereas the patches of broadleaved forest seem to be the least isolated. The largest nearest-neighbour standard deviation found for mixed forest implies a more irregular or uneven distribution of patches; the small value for the broadleaved class implies a more uniform or regular distribution of patches across the landscape.

WOODLAND RESTORATION

One of the earliest recommendations for landscape restoration arising from studies of habitat fragmentation was the proposal that fragments that are linked by a corridor of similar suitable habitat are likely to have greater conservation value than isolated fragments of similar size (Diamond, 1975). In Britain, the findings of Dawson's review (1994) support those who stress that the retention, enhancement or provision of corridors should be balanced against alternative measures to conserve biodiversity, such as habitat improvement, species reintroduction or the enlarging of biological reserves. Kirby (1995) addressed the issue in practical conservation suggesting that a combination of approaches will be needed within the landscape, with the emphasis in parts being on linkage and elsewhere on the expansion of isolated patches of habitat. Kirby reached some practical conclusions, such as (1) where the extent and diversity of semi-natural vegetation is high, the emphasis should be on reducing edge effects by increasing the overall area of semi-natural vegetation wherever it is appropriate and improving management for nature conservation; (2) where semi-natural habitats are very sparse and the matrix is hostile the first priority is to build on what exists already and buffer the existing habitats to reduce external influences.

These two methods formed the basis of our GIS simulation in Snowdonia in order to study the changes to the fragmentation of broadleaved, mixed forest and scrub habitats. The GIS functions work in a completely objective manner, which could be useful in the initial strategic planning for the expansion of woodland cover. The experiment was done in two areas of 10km x 10km in size with different semi-natural woodland habitat characteristics. The first may be considered an example of Kirby's site type '1' above, and the second of site type '2'. Coniferous forest and improved pasture were considered as artificial features of the National Park's landscape that could be converted to a semi-natural broadleaved habitat without substantial losses in wildlife conservation value.

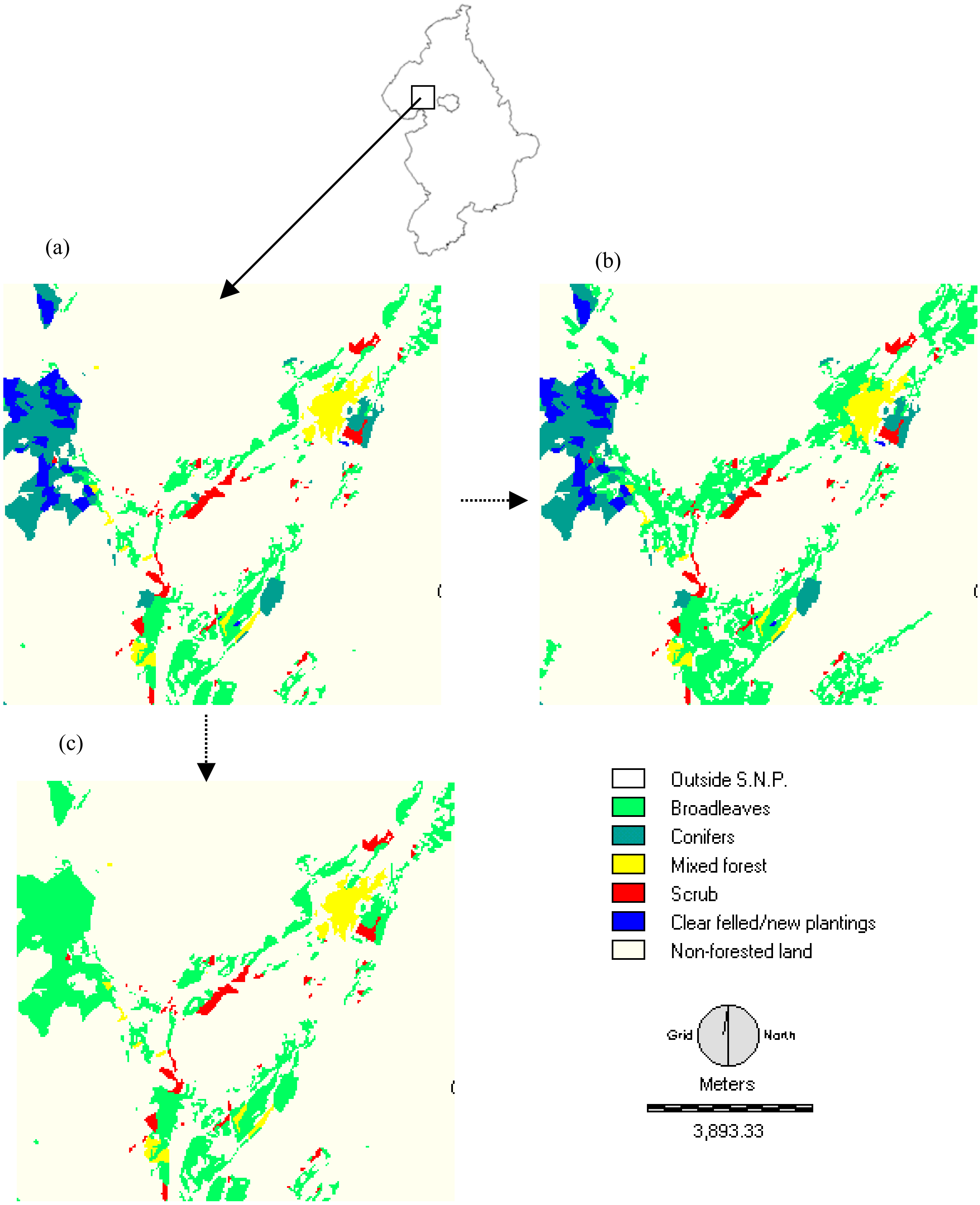

FIGURE 3. Forested areas in the first study site used within the National Park in the simulation experiment. The study site of 10 x 10 km size (a) as it is at present; (b) after expansion of broadleaves on agricultural land; and (c) after conversion of conifers to broadleaves (adopted from Gkaraveli *et al.*, 2001).

In the first study site (FIGURE 3), the expansion of the overall woodland habitat was considered to be the best strategy because the site contained a high proportion of woodlands of different types. It seemed that it was not necessary to minimise the impacts from surrounding land use. In addition, linkage between the three woodland classes was not critical as direct corridors may act as barriers to species of another habitat such as grassland or heathland (Kirby, 1995). The simulation experiment showed that conversion of conifers (including clear-felled areas) to broadleaves would dramatically increase the broadleaved area (+92%) and the interior habitat (+618%, using an edge width of 100m) (TABLE 2). In contrast, the expansion of broadleaves on agricultural land would increase habitat area by 84% and the number of fragments would decrease, suggesting a more continuous habitat, and a better connectivity between fragments, but with less core area. This results from broadleaved patches being scattered in agricultural land in the lowlands, whereas the majority of conifers exist in the uplands. It seems that a combination of approaches, increasing broadleaved woodland on agricultural land and in former coniferous areas, would be the most appropriate solution.

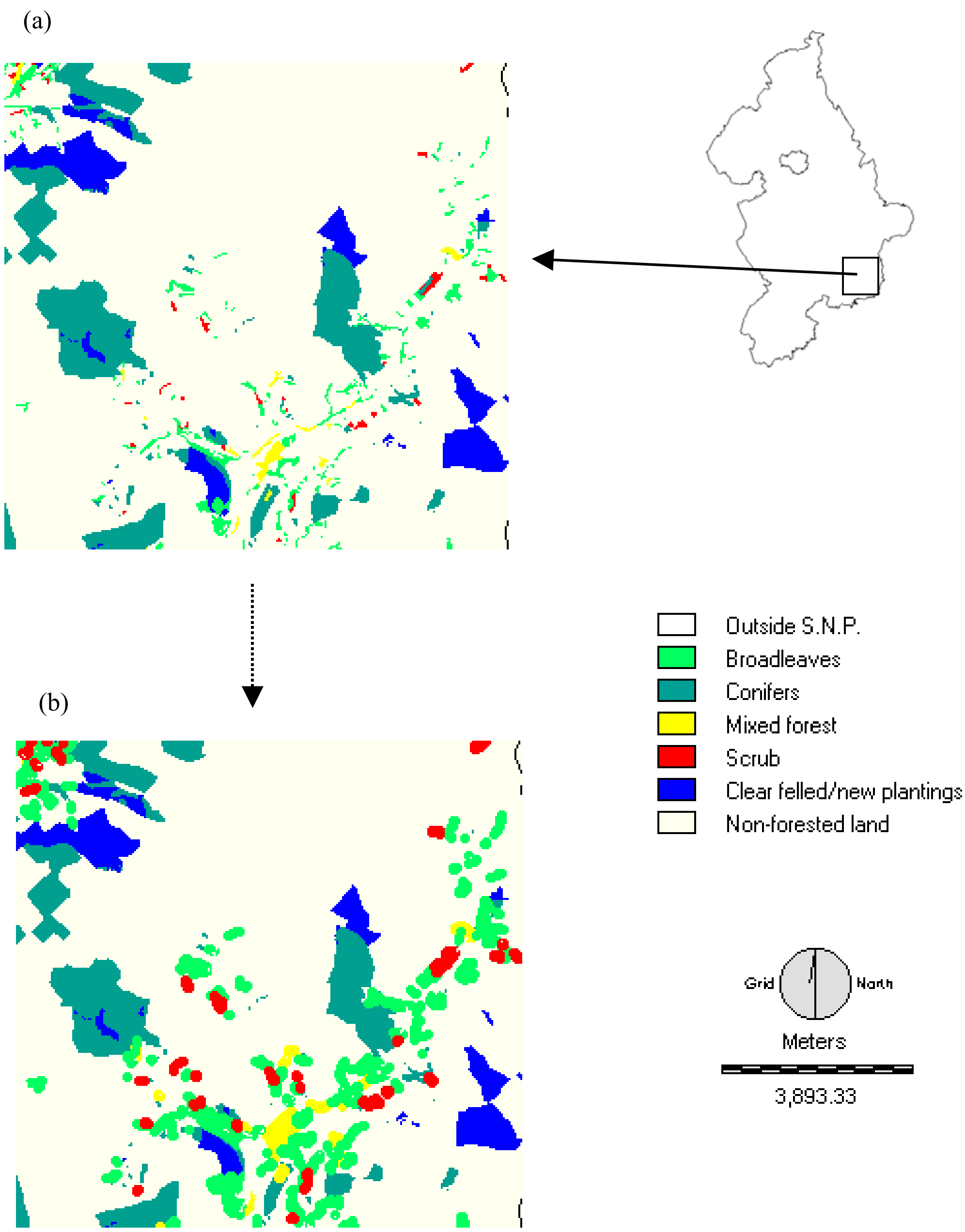

FIGURE 4. Forested areas in the second study site within the Park in the simulation experiment. The study site of 10 x 10 km (a) as it is at present; and (b) after adding a buffer zone of 100m around woodlands (adopted from Gkaraveli *et al.*, 2001).

In the second study site (FIGURE 4), the woodland habitats were found in a great number of very small and similar-sized patches, especially broadleaves and scrub (TABLE 3). The proportion of semi-natural habitats was low so it was assumed that the matrix would be hostile for some species. In this situation, a buffer zone is likely to reduce external influences (Bennett, 1999) and make the enlarged patches easier to manage (Kirby, 1995). The simulation results show that adding a 100m buffer zone of a similar habitat, would expand class areas by as much as 302% in broadleaves, 123% in mixed forest and 467% in scrub respectively. Habitats would be less subdivided into patches with less complexity in shape and with larger core areas. These buffer zones would change the extents of other land cover in the area, including some non-woodland semi-natural habitats; this could be minimised in practice by avoiding the expansion of woodland onto other important habitats.

TABLE 2. The simulated results of the conversion of conifers or agricultural land to broadleaves, and the spatial characteristics of the broadleaved fragments in the first study site (the present situation 'Before' of broadleaved fragments and the situation after the hypothetical conversion 'After' are given).

	Before	After	
	Broadlea	Conversion of to broadleaves	Conversion of pasture to
CA of conifers	639.36		639.36
CA of imp. pastu	584.64	584.64	
CA of	696.32	1335.68	1280.96
NP	103		
MPS (ha)	6.76	12.72	14.39
PSSD (ha)	14.79	51.68	56.44
MSI	1.66	1.67	1.71
TCA (ha)	54.88	394.24	146.40
MNND (m)	125.25	108.15	88.31
NNSD (m)	270.84	198.49	118.05

TABLE 3. The simulated results and spatial characteristics of broadleaved, mixed high forest and scrub fragments in the second study site, after creating a buffer zone of 100m around each patch (the present situation 'Before' of each class and the situation after the hypothetical buffering 'After' are given).

	Before			After buffer zone		
	Broadlea	Mixed	Scrub	Broadlea	Mixed	Scru
CA	227.36	50.72	41.60	915.04	113.28	235.
NP	130		34			
MPS	1.75	3.17	1.22	17.94	6.29	9.43
PSSD	2.81	4.10	1.21	26.39	8.67	4.88
MSI	1.46	1.70	1.36	1.49	1.37	1.25
TCA	0.64	0.80	0	104.96	13.92	13.7
MNND	137.94	1033.81	425.0	176.13	511.15	459.
NNSD	255.28	1592.93	449.7	346.69	789.08	426.

CONCLUSIONS

The combination of the IDRISI GIS system and the FRAGSTATS software proved to be a powerful tool for assessing the status of each forest habitat in the Snowdonia National Park. The FRAGSTATS spatial analysis program was used to compute several landscape indices and provided a full description of the pattern of each forest class in the landscape. In addition, the GIS helped to carry out the simulation experiment and examine the changes in habitats. This scenario analysis and further studies of this nature could be very useful in initial strategic planning for native woodland expansion.

According to this simulation experiment two approaches appear fruitful for the expansion of broadleaves, mixed forest and scrub habitats. First, the conversion of conifers to broadleaves or increasing the area of broadleaved forest on land under agricultural pasture would result in an expansion of the overall area of habitat, with a better connectivity between fragments. Second, the establishment of woodland buffer zones around fragments would enlarge them, increasing core woodland area and improving connectivity.

A replicated field experiment in Snowdonia, could complete the present study. It would be easy to identify sites, such as those selected in this experiment and try to decrease the fragmentation of habitats through the wide range of countryside schemes and initiatives. The landscape indices calculated in our analyses could be used to monitor the changes on each site as they provide a straightforward and effective means of landscape monitoring. Furthermore, similar studies of landscape structure may help to identify and prevent further fragmentation of habitats in the National Park and other areas where conservation and biodiversity priorities are high.

ACKNOWLEDGEMENTS
This work was assisted by support to A.G. from the State Scholarships Foundation (S.S.F.) of Greece.

REFERENCES

[1]Anon. 1998. *Wales Woodland Initiative-Strategy*. Report by Entec to the Countryside Council for Wales and the Forestry Authority (Wales). Entec, Leamington Spa.
[2]Atherden, M. 1992. *Upland Britain: A natural history*. Manchester University Press, Manchester.
[3]Bennett, A.F. 1999. *Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation.* IUCN, Gland, Switzerland and Cambridge.
CCW/FC Wales. 1999. *A living environment for Wales*. Published jointly by the Countryside Council for Wales and the Forestry Commission, Wales.
[4]Council of the European Communities. 1992. *The Habitat and Species Directive*. Council of the European Communities, Brussels.
[5]Dawson, D. 1994. *Are habitat corridors conduits for animals and plants in a fragmented landscape?* English Nature Research Report No 94. English Nature, Peterborough.
[6]Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. *Biological Conservation* **7**: 129-146.
[7]Eastman, J.R. 1997. *IDRISI for Windows, version 2.0 Student Manual: System Basics*. Clark University, Worcester, Mass, USA.
[8]Gkaraveli, A., Williams, J.H. and Good, J.E.G. 2001. Fragmented native woodlands in Snowdonia (UK): assessment and amelioration. *Forestry* **74**: 89-103.
Good, J.E.G., Bryant, R. and Carlill, P. 1990. Distribution, longevity and survival of upland hawthorn (*Crataegus monogyna*) scrub in North Wales in relation to sheep grazing. *Journal of Applied Ecology* **27**: 272-283.
[9]Kirby, K. 1995. *Rebuilding the english countryside: habitat fragmentation and wildlife corridors as issues in practical conservation*. English Nature Science No. 10. English Nature, Peterborough.
[10]Linnard, W. 2000. *Welsh woods and forests: A History*. Gomer Press, Llandyssul, Wales.
[11]McGarigal, K. and Marks, B. 1994. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure, version 2.0*. Unpublished computer program user manual and guide. Department of Forest Science. Oregon State University.
[12]Taylor, J. 1991. *Landscape change in the National Parks of England and Wales*. Report Vol. XII-Snowdonia. Silsoe College, Bedford.