MAPPING THE BROAD HABITATS OF THE BURREN USING SATELLITE IMAGERY

END OF PROJECT REPORT

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MAIN MESSAGES

- This project has successfully used satellite imagery to survey and map the extent and spatial distribution of broad habitat types within the Burren, and we have represented this information on a digitised habitat map.

- This map is the first to show the distribution of the broad habitats of the Burren and will be an important tool in aiding future decisions as to how the habitats of the Burren should be managed to the benefit of both the farmer and the environment. The map provides the first estimate of the area of the Burren affected by scrub encroachment – this being one of the most significant threats to the EU priority habitats in the region.

- On a particularly challenging area with a high diversity and complexity of habitats, remote sensing appears to offer a very effective and cost-efficient alternative to broad-scale habitat mapping on a field-by-field basis.

- The use of high-resolution imagery and ground-truthing should be adopted to complete a detailed national survey of habitats and land use in Ireland.

- This would support more effective implementation of both the Agriculture sector's obligations under the Habitats Directive, and agri-environmental schemes with wildlife objectives. The outputs provided by such mapping approaches could inform the targeting of agri-environmental objectives, and increase the efficiency of detecting areas of high conservation value for monitoring by more conventional methods.

- The detailed land use descriptions offered by such imagery are also of high relevance to modelling approaches and risk assessment for implementation of land use policies such as the Water Framework Directive and Nitrates Directive.

INTRODUCTION

Background and aims

The Burren, Co. Clare is an internationally important landscape, containing a high diversity of native vascular flora and a mosaic of important habitat types (EU Habitats Directive). There has been increased concern about changes in the extent, distribution and quality of habitats of conservation value, particularly in the karst region of the Burren. A number of threats are perceived to be affecting the extent, distribution and quality of ecological habitats in the Burren (Dunford and Feehan, 2001). The main threats include farm intensification and changes to the grazing management regime. These produce a variety of specific threats particularly under-grazing which is facilitating scrub invasion and is compounded by the feeding of silage.

While there is considerable anecdotal evidence about changes in the habitats of priority conservation value in the Burren, there is relatively little evidence based on objective data (but see O'Donovan, 1987; Dunford, 2001). Attempts to assess and research the nature and extent of the impacts of threats on the vegetation of the Burren are seriously curtailed by the absence of a large-scale baseline survey that makes data available in an accessible format. The aim of the proposed project is the provision of an integrated and comprehensive database (stored in digital form in a Geographical Information System) to facilitate agri-environmental evaluation and research in the Burren.

Mapping land use with satellite imagery

Satellite imagery has been used extensively for mapping habitats and land cover around the world, particularly in areas where field surveys would otherwise be difficult or impossible as in Arctic Russia (Virtanen, Mikkola, & Nikula, 2004). It is also becoming increasingly popular as a relatively quick method of assessing vegetation cover over large areas, where extensive field-work would be too costly or too slow. For instance, it has been used in Europe as an efficient method of mapping land cover on a repetitive basis (Commission of the European Communities, 1995), providing statistics on a range of land cover types throughout Europe, particularly for agriculture.

In the past there has been difficulty with reconciling traditional phytosociological and other vegetation classification methods with satellite imagery (e.g. Kalliola & Syrjanen, 1991). This is because vegetation classification rarely takes into account topography, geology, soil moisture and other seasonal factors such as sun angle, all of which influence reflectance values from satellite images. Some of these problems may be corrected by: using Digital Elevation Models (DEMs) to inform the 3D nature of the topography (Nilsen, Brossard, & Joly, 1999); using a PCA of the image (Kalliola & Syrjanen, 1991) and; using image-ratio techniques such as Normalised Difference Vegetation Index (NDVI) to enhance observation of differences in vegetation productivity. Multi-temporal data can also provide more comprehensive information than just one image date. As a result, it is possible to get up to 85% correlation with phytosociological data e.g. in Argentina (Zak & Cabido, 2002) and Syria (Hirata *et al*., 2001). Studies within the British Isles have used imagery from simply locating sampling sites for vegetation survey (Kent *et al*., 1994) through to classifying landscapes using multivariate techniques (Haines-Young, 1992). Land cover mapping at the national level in the UK has utilised Landsat TM imagery for mapping broad habitat types (Fuller *et al*., 2005). Land cover in Ireland has been mapped as part of an EU-funded CORINE initiative using Landsat TM satellite imagery (Cruickshank & Tomlinson, 1996) and this is being updated regularly.

There has been little published work on habitat mapping within Ireland using satellite imagery (Betts Cruickshank & Tomlinson, 1986, Coveney & O'Donovan, 2001), but there has been work on mapping soils using SPOT imagery (Cruickshank & Tomlinson, 1988) and more recently, carbon stores derived from land cover categories compiled using satellite imagery (Cruickshank Tomlinson & Trew, 2000). The use of satellite imagery to classify lowland grasslands in Ireland has been explored in a pilot study (O'Donovan, 2004). It highlighted the difficulties of identifying semi-natural grasslands, particularly wet grasslands, but accuracies were good for semi-improved and unimproved dry grasslands that were sampled adequately in the field.

OBJECTIVES

This study was initiated to use satellite imagery to classify the broad habitats of the Burren, a unique area of karst landscape in the West of Ireland. Much of this area is designated as Special Area of Conservation (SAC) for its limestone pavement and limestone grassland of conservation interest. Due to the size of the area, a full field survey would be expensive and time-consuming (O'Donovan, 2004). There is concern also that scrub is encroaching on the species-rich grasslands and that it has expanded quite quickly over recent decades (Dunford & Feehan, 2001) but there are no accurate records of the area that scrub has covered in the Burren. These grasslands are kept in favourable condition by the system of grazing which has been practiced for centuries in the Burren which involves grazing over the winter period on low to medium productive grasslands and heaths (winterage) and cessation of grazing over the summer period (Haughton, 1953). Since the advent of modern agriculture however, heavier breeds have been introduced into the Burren along with supplementary feeding and this has reduced the amount of time that cattle spend on these winterages (Dunford & Feehan, 2001). This study was run in parallel with a survey to classify the vegetation of the grasslands and heaths of high conservation value that were found within the study area. Apart from mapping the broad habitats of the Burren, a more specific aim of this study was to see how well the vegetation classification matched the grassland and heath categories mapped by the satellite imagery.

The specific objectives of this study were:

Objective 1: To use satellite imagery to survey and map the extent and spatial distribution of broad habitat types within the Burren, and to represent this information on a digitised habitat map.

Objective 2: To describe the vegetation composition of broad habitat types identified in Objective 1, which will aid development of the digitised habitat map.

Objective 3: To survey quantitatively the habitat and species composition of selected field-scale sites of conservation interest in the Burren. This will establish a series of monitoring sites with baseline quantitative vegetation data against which future change can be measured. It will also increase knowledge of some of the vegetation communities and sub-communities found in the grasslands and heaths of conservation value within the Burren and the ecological gradients driving these communities.

The Study Area

The study area encompasses the karst region of North Clare is often referred to as the high Burren. The western boundary is defined by the coastline from Doolin to Blackhead and the northern boundary by the coastline from Blackhead to the foot of Corker Pass. The eastern boundary runs from the coast at the foot of Corker Pass along the New Line road to the point at which it intersects the R460 at Lough Bunny. The southern boundary follows the R460 from Lough Bunny east toward Corofin at which point it begins to follow the approximate line of the limestone-shale boundary running south of Kilnaboy, taking in Kilfenora before skirting Lisdoonvarna. Going north it passes around the shale of Slieve Elva before turning south to join with the western boundary at Doolin. The total area encompassed is approximately 384 square kilometres or 38,413 hectares (Fig. 1).

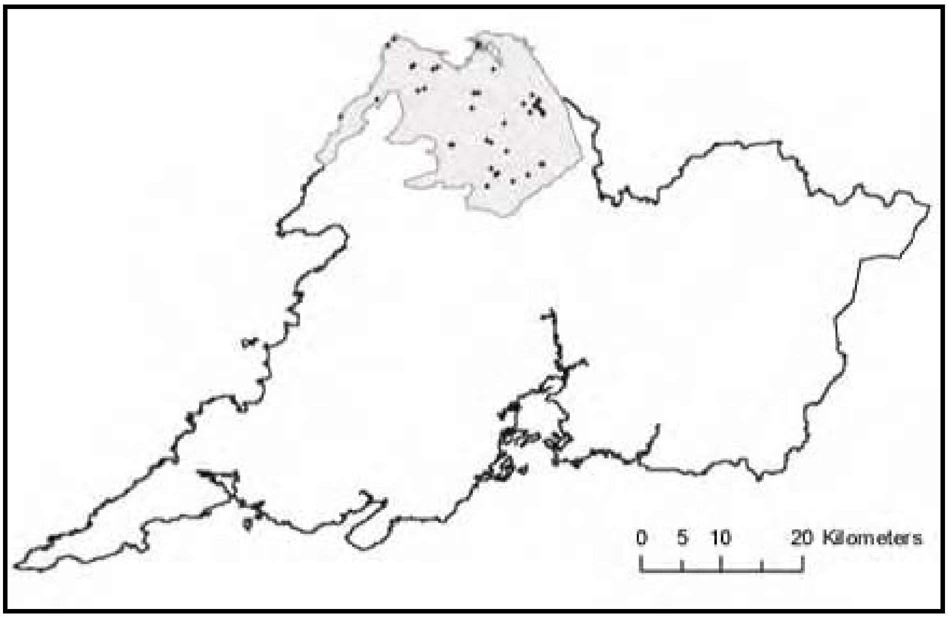

Fig.1. Map of County Clare with study area in grey, showing the limits of the Burren karst area of this study. Sample sites (for Objective 3) are shown as black dots.

The parent rock is carboniferous limestone which has been subjected to at least two documented glaciations (Farrington, 1965). As a result, there was a blanket of glacial till over the landscape and the area became wooded. In late Neolithic times, woodland was much reduced by the farming community and the species-rich grasslands came into being. In the Bronze Age, weather deteriorated and the soils were stripped away, leaving areas of bare karst and mostly thin soils throughout (Feehan, 2003). The average annual temperature is 10°C and annual rainfall can reach up to 2000 mm (O'Donovan 1987). The area is subject to few frosts but despite the high rainfall, can be prone to drought in the summer months (Webb & Scannell, 1983; O'Donovan 1987; Osbourne, 2003).

METHODOLOGY AND RESULTS

The rationale for mapping the Burren area is to reduce the amount of field work required in the future for mapping habitat types and monitoring vegetation change in an area of conservation importance. The most useful, value-for-money imagery at this scale is the Landsat series as it has the best range of infra-red (IR) bands most appropriate for mapping vegetation. Imagery from SPOT satellites was considered as an alternative, but although the multispectral bands of SPOT 5 have a higher resolution (20m colour) than those of Landsat 7 (30m colour), it collects fewer spectral bands and is more expensive. May is considered to be the best month for separating vegetation classes. With this in mind, two images were used initially to inform fieldwork; a Landsat 5 image from May 1999 and a Landsat 7 ETM+ image from April 2003. Unfortunately, a recent May Landsat 7 image was not available for this study as those from preceding years had too much cloud cover and after April 2003, Landsat 7 ETM+ subsequently developed a technical problem, rendering images of little use for this study.

First, a potential habitat map was created by conducting a 15 class unsupervised classification of the May 1999 Landsat 5 image and subsequently when it became available, of the April 2003 Landsat 7 ETM+ image~~s~~ in Erdas Imagine 8.6. From these, a crude habitat classification was arrived at to inform ground-truthing. These included water bodies, plantation forestry, improved grassland, tillage, sand dunes, scrub/woodland, several types of unimproved grassland and limestone pavement. Clouds, cloud shadow and cloud haze also formed distinct classes in the April 2003 image. Extensive fieldwork was then carried out in the field season of 2003 and to a lesser extent in 2004 with habitat data being collected for approximately 850 individual points (Fig. 2). In the majority of cases a GPS reading was taken at a point deemed to be representative of a particular habitat, a brief description made of the habitat and the vegetation in the immediate vicinity. In addition, some large areas of habitat (usually scrub or limestone pavement) were observed from vantage points and their position marked using a combination of the Ordnance Survey map and the habitat map created using the unsupervised classification. These data were then overlaid on the images and the unsupervised classification in both Erdas and ArcGis in order to aid interpretation.

A supervised classification was carried out on the basis of the ground truth data collected. From this, a habitat map was derived with the final habitats being: water bodies and lacustrine vegetation, sand-dunes, blanket bog and wet heath, tillage, conifer plantation, clear-felled forestry, improved grasslands, stronger winterage (more productive calcareous pastures with mesotrophic elements and mesotrophic winter-grazed pastures), weaker winterage (less productive, calcareous winter-grazed pastures), scrub, limestone pavement, vegetated limestone pavement, *Calluna* heath/open scrub, drying turloughs, MG10 type grassland.

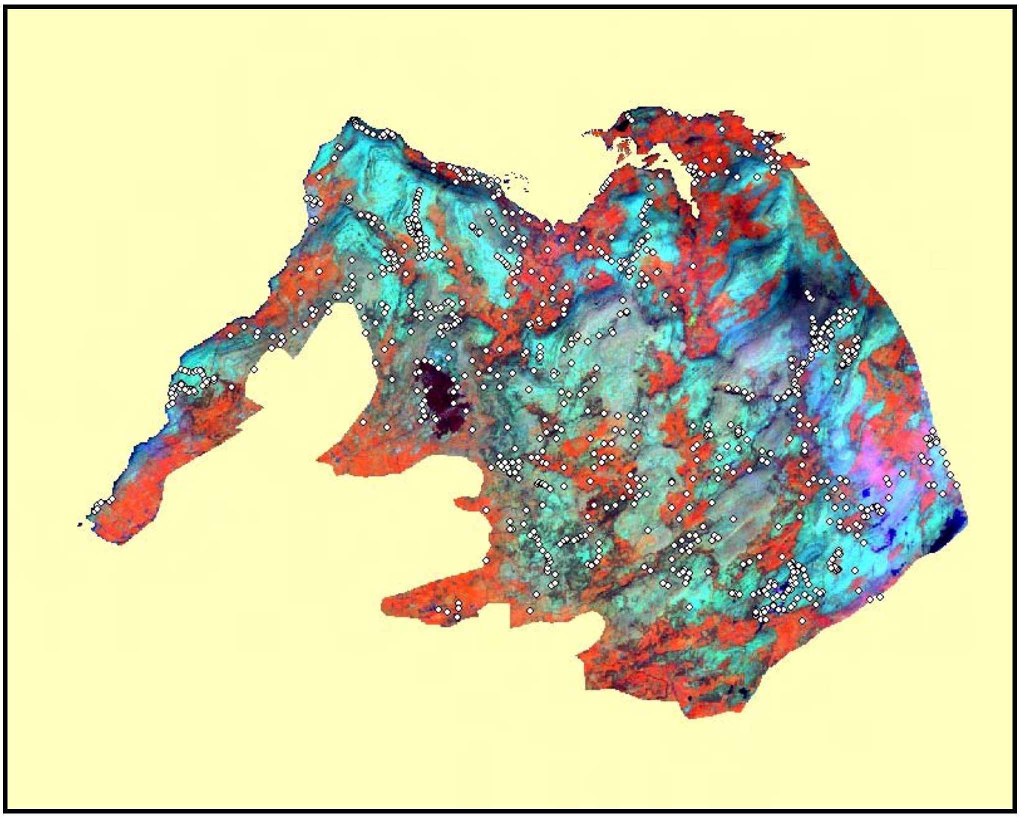

Fig. 2 Vegetation data were collected from 850 sites (white dots). The site locations are superimposed here on a Landsat image of the study area.

Descriptions of habitats mapped in the Burren area are provided here. These include a definition of the habitats classified and the methodology used to build up the habitat map to the final output.

Water bodies and lacustrine vegetation

This category includes all water bodies, both permanent and temporary, with standing water in April 2003 as detected by satellite and a small band of the sea along parts of the coast. These were mapped using the red, near IR and two mid IR spectral bands (bands 3, 4 5, and 7) of a masked, non-topographically normalised April 2003 image. This image was created by using an 8-class, unsupervised classification of a NDVI (Normalised Difference Vegetation Index) of the April 2003 image to mask out all areas other than those deemed to have no or very sparse vegetation. These included only water, limestone pavement and vegetated limestone pavement. The masked image was classified by means of a supervised classification using training signatures collected for water and pavement from the image. Whilst the differentiation of water and limestone pavement was good due to their very different spectral signatures, the opportunity was taken to correct a potential inaccuracy noted during early classifications where tall, emergent lacustrine vegetation was often classified in the scrub class. This adjustment was feasible due to the relatively small area of water in the study area. As the area of lacustrine vegetation was too small to provide sufficient training signatures and there is considerable overlap between its spectral signatures with that of scrub, the following technique was used. The classified image was overlain on the original April 2003 image and the water bodies expanded to take in the areas of tall, lacustrine vegetation both at the margins and where present, within the body of the water. The expansion was carried out based on visual interpretation of the image in conjunction with the Area of Interest (AoI) seed tool in Erdas Imagine. Subsequently, the new expanded water bodies were overlaid onto the Ordnance Survey map to aid further minor adjustments before being checked against the April image once more. A water body AoI was created to mask out water bodies in subsequent classifications of the imagery. The mapping of the water bodies and associated lacustrine vegetation was carried out before the data was obtained to allow topographic normalisation of the images when deep shadows could be incorrectly classified as water. However, the subsequent manipulation to improve the accuracy of the mapped areas validated its use in the final habitat map.

Dunes, tillage and drying turloughs

Dunes are a rare and restricted habitat within the Burren, occurring only at Fanore and Bishopsquarter. The habitat includes both fixed and mobile dunes as well as dune slacks. The Burren contains a very small area of tillage restricted to the deeper soils in some of the valleys and on the north coast. The area of tillage shown on the map is underestimated as it only includes areas where the soil was bare in April 2003 and excludes emergent crops such as sugar beet and winter wheat. These could not be differentiated from other habitats, particularly grasslands as the area of the crops was too small to obtain sufficient training signatures. Many of the turloughs (temporary dry lakes) that contained water in April 2003 are included with water bodies as it is difficult to differentiate between permanent and temporary water bodies using Landsat imagery (without using multi-temporal analyses). The data for turlough distribution is available through the National Parks and Wildlife Service. This category is restricted to those turloughs which were wet but did not contain standing water in April 2003 and as such is an underestimation of this priority habitat. As the area of drying turloughs was so small, it was impossible to acquire sufficient training signatures to be used in a supervised classification. However, drying turloughs appear bright green when the satellite image is displayed with bands 4, 5, 3 in the RBG channels respectively so they could be selected by eye and classified separately.

The habitat types of dunes, tillage and turloughs cover a very small part of the study area, and therefore precluded the collection of sufficient training signatures for use in a supervised classification of the whole study area without the introduction of significant inaccuracies in the map. In order to overcome this problem, an Area of Interest (AoI) was created for dunes, tillage and drying turlough. This involved using the polygon tool in Erdas Imagine to draw around the areas where these habitats occurred, based on field data and visual interpretation of the April image. The AoI was overlain on top of a topographically normalised April 2003 image comprising the red, near IR and two mid IR spectral bands and signatures collected from within the AoI for each of the habitats. Following a supervised classification of the AoI area, any 'rogue' pixels were corrected by hand. Again, as with the water bodies, this was only possible due to the small areas involved.

Forestry

An isolated area of shale-capped limestone occurs within the study area encompassing Poulacapple, Greggan's Wood and close surrounds. The area covered was too small to obtain sufficient training signatures at the scale of the whole Burren, particularly as the plantation forestry present consisted of both spruce and the deciduous larch. Rather than excluding this area from the map, an Area of Interest (AoI) subset image was created for this and two other small, isolated areas containing forestry and classified in isolation from the rest of the study area. The following habitats occurred here: mature conifer plantation, clear-felled plantation, adjacent blanket bog, wet heath and MG 10 type grassland (NVC classification of *Holcus lanatus-Juncus effusus* rush-pasture - poorly drained pasture with a high cover of *Juncus* species). The plantations are easily discerned by eye from the imagery when the Near IR (4), Mid IR (5) and Red (3) spectral bands of the April 2003 image are displayed in the RBG channels respectively. A supervised classification of the above AoI was then carried out using signatures collected from the afforested areas, blanket bog/wet heath, clear fell and MG10 rush pasture to provide a map of these habitats.

Improved grassland

These are principally grasslands subject to a variety of practices associated with more intensive agriculture including addition of artificial fertilizer and/or farmyard manure, reseeding, intensive grazing particularly in late spring, summer and early autumn and production of silage and/or hay crops. From A Guide to Habitats in Ireland (Fossitt 2000), it includes grasslands that fall into, or approximate to, the following classifications - GA1 (Improved agricultural grassland) and GA2 Amenity grassland (improved). From the NVC (National Vegetation Classification) they may be classified into MG6 *Lolium perenne-Cynosurus cristatus* grassland (which grades into a relatively species poor MG5 *Centaureo-Cynosuretum* grassland on thinner soils where intensification is more or less limited to summer grazing), MG7 *Lolium perenne* leys and MG10 *Holcus lanatus-Juncus effusus* rush-pasture.

Improved grasslands are usually found on deeper soils in valleys and coastal areas but also on isolated improved drumlins (Fig. 5). Some improved grassland on thin soils is included in the 'Stronger winterage' category (see below) probably due to the influence of the thin soil cover on the spectral signature of these areas. Generally these are productive grasslands that are relatively species-poor and usually excluded from cSACs. The 'improved grasslands' class was then used as a mask to help delineate the semi-natural grasslands more easily.

To do this, an April 2003 image file was created that contained only the Red, Near IR and two Mid IR bands (bands 3, 4, 5 and 7). The forestry, dunes, tillage, drying turloughs and water AoIs outlined above were used to mask these habitats from the image by using the raster tools to adjust the pixel values to zero. Signatures were collected from representative areas as determined by GPS-referenced habitat data collected in the field for the following habitats: improved grassland, scrub, mature/senescent *Calluna* heath, higher productivity winter-grazed pastures (stronger winterage), lower productivity winter-grazed pastures (weaker winterages) and limestone pavement. Having examined the resultant supervised classification alongside the unclassified image and GPS referenced habitat data, the following conclusions were reached; the areas classified as improved grassland corresponded well with field data and the high biomass categories of an NDVI created using the April image. The area of weaker winterage was overestimated and that of vegetated limestone pavement underestimated due to the problems of selecting good training sites for these habitats, a factor complicated by their spatial complexity. The area of scrub was probably being underestimated due to the lack of leaf canopy in April, leading to the background habitat dominating the spectral signature, particularly in areas of lower, more open, immature scrub.

It was decided, therefore, to try to further improve the accuracy of the mapped areas of winterage, scrub and limestone pavement areas by further pre-processing of the imagery while accepting the area mapped as improved grassland for use in the final map.

Scrub and woodland

This category encompasses both scrub and ash-hazel woodland (the latter a relatively infrequent habitat in the Burren at the current time). The predominant type of scrub in the Burren is dominated by *Corylus avellana* (hazel) but there are smaller, less frequent areas dominated by *Prunus spinosa* (blackthorn), *Crataegus monogyna* (hawthorn) and *Ilex aquifolium* (holly). Areas of mixed scrub are most frequent on the North coast.

The scrub category includes mature scrub with a more-or-less continuous canopy, mature scrub within a grassland matrix similar to a gladed wood pasture (scrub cover is usually greater than 50%), immature scrub with a continuous or broken canopy that commonly ranges from approximately 1.5m to 3m in height. It was not possible to separate woodland from scrub and the different types of scrub using satellite imagery.

Various experimental approaches were used to try to boost the visibility of the scrub in a base image which could then be used to map this habitat. Success was achieved when a new, combined image was created using the Near IR (4) and Mid IR (5) bands from the April 2003 image and the Near IR band (4) from the August 2003 image. When displayed as April Near IR (4) in blue, April Mid IR (5) in green and August Near IR (4) in red, the scrub and woodland became highly visible. The previously mapped water bodies, forestry and associated habitats, dunes, tillage, drying turloughs and improved grassland were masked out leaving only the scrub, winterages and limestone pavement in the new base image. The areas affected by cloud shadow and cloud haze were also masked out. Training signatures were collected for scrub and woodland, stronger winterage, weaker winterage, limestone heath with mature/senescent *Calluna*, limestone pavement and vegetated limestone pavement and a supervised classification carried out (Fig. 3). Comparison of the areas classified as scrub and woodland with the combined image and GPS referenced field data suggested that the resultant map was a relatively accurate representation of this habitat.
However, the same was not true for the other habitats, so further processing was necessary to elucidate their extent and distribution.

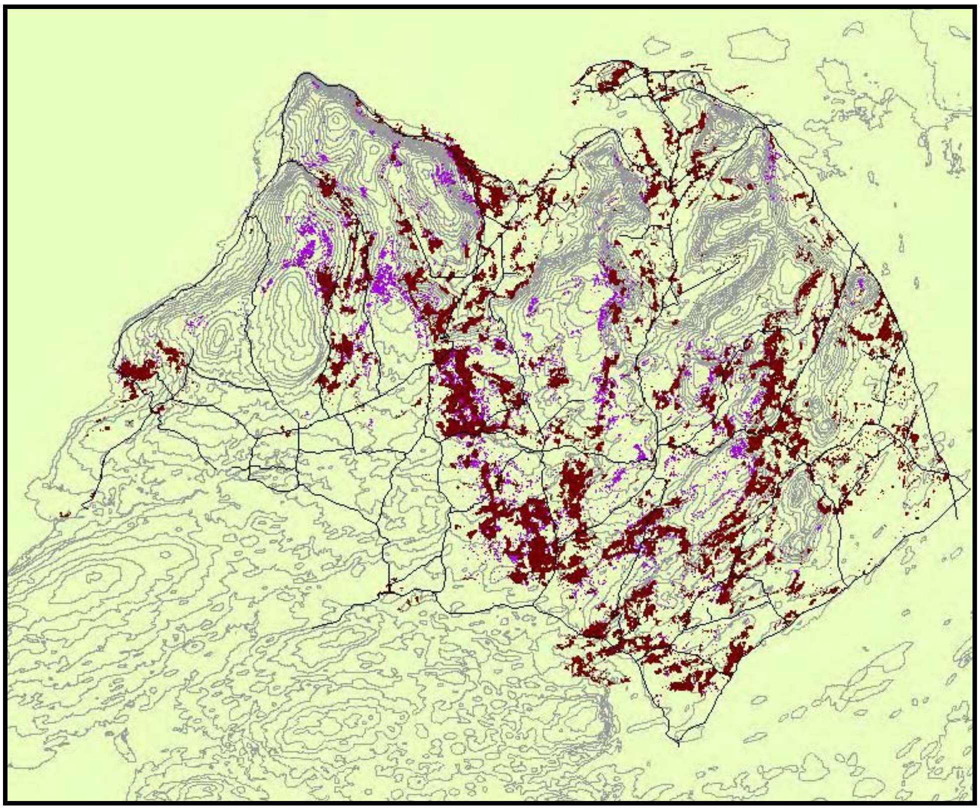

Fig. 3. An example of habitats identified from satellite imagery in the Burren. Woodland and closed canopy scrub are seen here as dark brown. *Calluna* heath and low open scrub are shown in purple.

Limestone pavement and vegetated limestone pavement

Limestone pavements are areas of exposed limestone, with a surface of either clint and grike structure or shattered limestone. It is usually very sparsely vegetated (generally < 10% cover) which is restricted to grikes or small islands of soil. Vegetated limestone pavement is described as limestone pavement having vegetation cover usually less than 50% but this may increase to 70% where the soil and vegetation cover is very thin and the rock affects the spectral signature. It can occur with islands of vegetation or vegetated grikes. Sometimes it occurs with dispersed low scrub of *Corylus avellana, Prunus spinosa* and/or *Crataegus monogyna*. It also includes pioneer *Dryas* communities.

The spectral signature of the rock in limestone pavement, whether as exposed clints or loose rock, tends to dominate even in the presence of skeletal soils. Concerns regarding the poor separation of the weaker winterages from vegetated limestone pavement led to the

Normalised Difference Vegetation Index (NDVI) being used to help separate limestone pavement from vegetated limestone pavement. NDVIs were prepared for both the April and August 2003 images (neither of which had been topographically normalised). Unsupervised classifications of each of these images were carried out, which divided them into eight different categories which reflect biomass and photosynthetic activity. On comparison with the base images and field data, two of these categories were found to correspond well with bare limestone pavement and vegetated limestone pavement respectively. However, the April 2003 image was found to overestimate vegetated limestone pavement by including some areas of *Dryas* and *Calluna* heath in this category. This was possibly due to low photosynthetic activity at this time, so the classified August 2003 NDVI was used to map the two categories of limestone pavement instead (Fig. 4). Slight adjustments had to be made to correct areas of improved grassland that had been recently harvested for silage as these appeared in the vegetated limestone pavement category. The correction was facilitated by the fact that improved grasslands have defined boundaries visible in the base imagery while pavement does not.

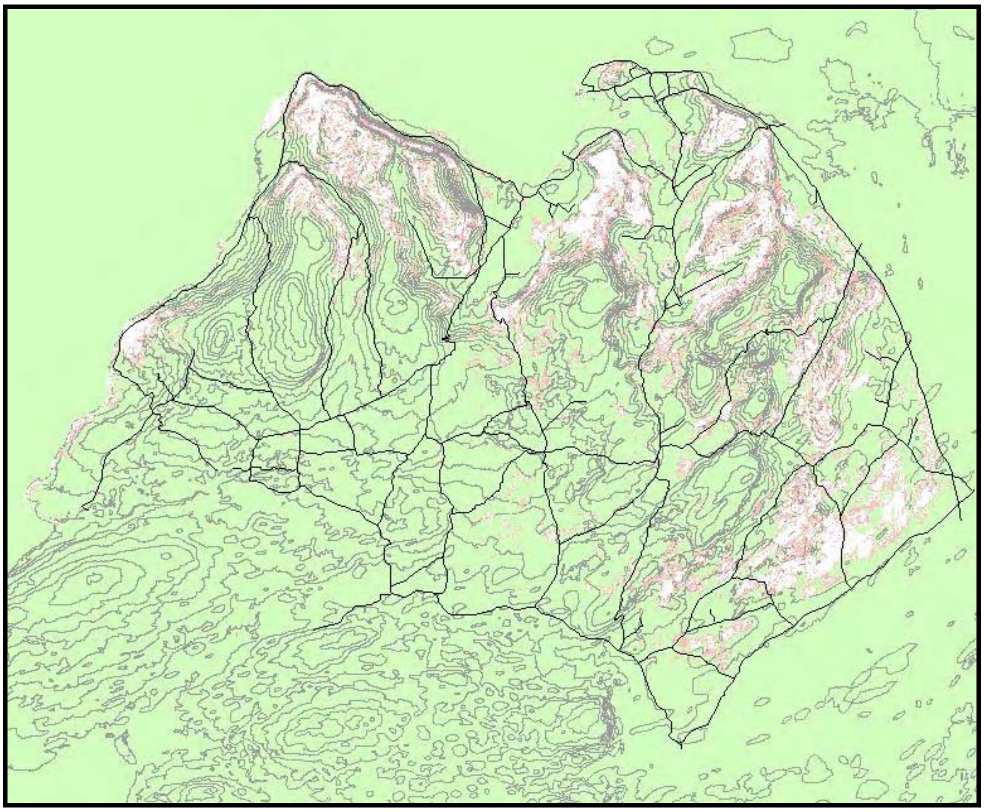

Fig. 4 Map of limestone pavement (white) and vegetated limestone pavement (pink) in the study area.

Winter-grazed pastures including stronger and weaker winterages and mature/senescent Calluna heath

The final habitats to be mapped were the winter grazed pastures. An image was produced in which all the previously described habitats were masked out and the training signatures collected prior to masking used in a supervised classification. This resulted in a map which split the winterages into those that were of higher agricultural productivity (stronger), lower agricultural productivity (weaker) and included areas with significant cover of mature/senescent *Calluna*.

Weaker winterages are generally of very low agricultural productivity. They are managed as winterage (grazed in the winter between 1st October and 30th April for all or part of that period) with little or no summer grazing and no artificial fertilizer or farmyard manure inputs. They are usually on very thin soils with up to approximately 50% limestone exposure. They include a range of low productivity grasslands and limestone heaths where *Sesleria caerulea* is the dominant grass or is co-dominant with *Festuca rubra*. They also include *Dryas octopetala* heath and the less widespread *Dryas octopetala-Empetrum nigrum* heath. They are generally dry, calcareous, often very species rich and diverse. At their extreme they grade into vegetated limestone pavement (Fig. 5).

Stronger winterages are predominantly grasslands that are managed according to the tradition of 'winterage' whereby stock grazing is restricted to a period between October and May although there may also be some relatively light summer grazing on some of these grasslands. It also includes a limited area of low productivity improved grassland e.g. areas that are managed intensively but their productivity is compromised by factors such as being prone to drought due to thin soil cover. Fertilizer inputs may have been used in the past and there may have been more summer grazing historically. These grasslands are less productive than the improved grasslands but are more species-rich. They often occur on unimproved drumlins and glacial till, or hill plateaux where there is a better soil cover and/or the clay content of the soil aids water retention. They are more mesotrophic in character than the weaker winterages but often contain significant calcareous elements and are occasionally leached leading to the development of a more 'acidic' flora. More productive and vegetationally distinct from the weaker winterages, *Festuca rubra* dominates along with other grasses commonly found in meadows e.g. *Anthoxanthum odoratum, Dactylis glomerata,* *Cynosurus cristatus.* They may also encompass limestone heath where the cover of *Calluna vulgaris* exceeds 25% but the height of the *Calluna* is generally <0.3m tall due to grazing (Fig. 5).

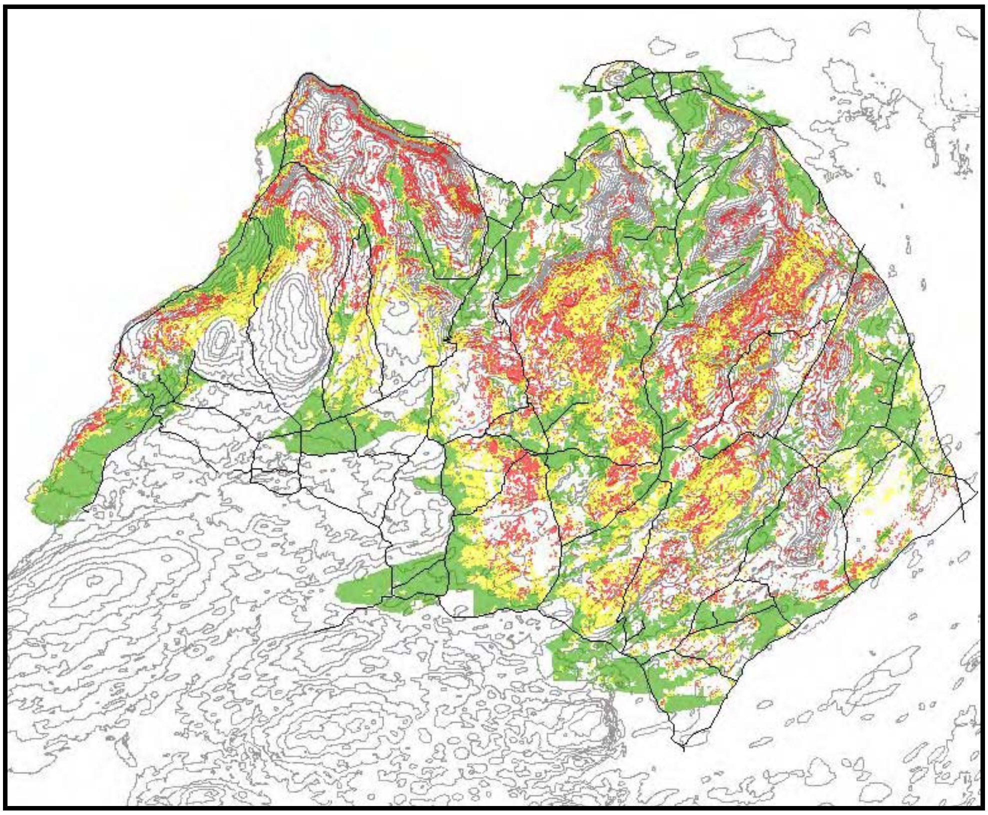

Fig. 5 Habitat map of the study area showing improved grasslands (green), strong winterages (yellow) and weak winterages (red).

Stronger winterages include a range of grassland and heath types that fall into, or approximate to, the following classifications. According to Fossitt (2000) the stronger winterages may be defined as GS1: Dry calcareous and neutral grassland (extensive distribution), GS4: Wet Grassland (limited distribution, GM1: Marsh (very limited distribution), HH2: Dry calcareous heath (widespread), HH3: Wet heath (very restricted). From the National Vegetation Classification (Rodwell 1992), they may be classified as MG5 *Centaureo-Cynosuretum* (grades into MG6 in some areas due to summer grazing) and MG10, *Holcus lanatus-Juncus effusus* rush-pasture.

Mature/senescent *Calluna* heath includes both *Calluna* heath which has become mature or senescent (*Calluna* generally over 0.5m in height) and low, open scrub (Fig. 3). On comparing the extent of mature/senescent *Calluna* heath with field data on its occurrence, it became apparent that there was a certain amount of crossover between this heath category and low, open scrub. No satisfactory way of separating these two habitats was found using Landsat imagery. However, other than perhaps using aerial photographs to aid interpretation, the following rule of thumb can be used to allocate an area to the most probable habitat type - if on a north or north-west facing steep slope or on a plateau, it is most likely to be mature/senescent *Calluna*, whereas if it is close to areas of scrub or woodland, it is most likely to be low, open scrub.

In many mapping projects the norm is to smooth the final classified image to exclude areas of habitat below a certain area, often 1 hectare in the case of Landsat imagery. Early work indicated that while smoothing the map did indeed remove small spurious pixels, it introduced many inaccuracies as well, particularly in an area such as the Burren which consists of an intricate mosaic of habitats. While the map indicates whether an area contains stronger or weaker winterage, it must be recognised that this can only be taken as the most likely, rather than the definitive situation as these two broad habitats inter-digitate extensively

Areas affected by cloud shadow and cloud haze

Ground truthing of the 15 class unsupervised map created using the April 2003 image indicated that the separation of habitats was good but several problems were highlighted. A thin cloud haze affected a small area to the east of Mullaghmore making the classification of this area inaccurate. A cloud south east of the study area cast dense shadow over Slieve Carran making it impossible to map this area using this particular image.

There was concern that inaccuracies would arise due to scrub and woodland not being in leaf at the time of the April 2003 image. This led to the purchase of a second image from August 2000; the latest date for which cloud-free imagery was available. While the August 2000 image was free of cloud and cloud shadows, its potential for use in mapping the broad habitats of the Burren was found to be limited. The good separation of the winter-grazed pastures from the more intensively farmed grasslands achieved using the April image was lost as the winterages had increased biomass due to being fallow over the summer whilst much of the intensive pasture had been heavily grazed or cut for silage, thus reducing their biomass. There was also overlap between some of the less mature scrub and the grasslands. However, it did provide a means of classifying the area east of Mullaghmore affected by cloud haze and that of Slieve Carran affected by cloud shadow. Hence, in the final map, the habitats in the cloud haze and cloud shadow affected areas were mapped using a supervised classification of two subsets of the August 2000 image. Signatures were collected separately for each subset for use in the supervised classification. Examination of the resultant habitat map showed that some areas had been wrongly categorised due to the higher biomass later in the year i.e. some stronger winterages were classified as improved grassland and some weaker winterages as stronger winterage. As the areas involved were small and good field data was available, these inaccuracies were corrected by hand using the raster tools.

Satellite imagery and map creation

The habitat map was created using the two Landsat 7 ETM+ images with a resolution of 30m. In order to create the final map, each individual habitat as described above was run through a 'raster to vector transformation' in Erdas Imagine and exported to ArcGis 8.2. The final map was reassembled using all the vector representations of each habitat (Fig. 6).

A significant problem encountered during the early stages of map creation was that caused by the position of the sun at the time of the satellite pass i.e. south east of the study area. The Burren has a very varied topography of hills and valleys, and the sun position at the time of image acquisition meant that north and north-west facing slopes in the Burren were in shadow. When classified by means of an unsupervised classification, this had the effect of some areas of deep shadow being classified incorrectly as water, and the inclusion of a shadow class which gave no indication of the habitat present and overestimation of scrub on north and north-west facing steep slopes. It also introduced inaccuracies into the supervised classification by increasing the variation in the range of spectral signatures that represented any given habitat. As with the unsupervised classification, it lead to an overestimation of scrub on the northern slopes and areas being incorrectly classified as water. To overcome this problem, the topographic normalisation feature in Erdas Imagine was used to simulate the spectral signature that would be obtained if the sun were directly overhead i.e. the position of the sun was altered to remove the shadow effect. Whilst largely successful, a small number of areas that were in very deep shadow e.g. north facing, near perpendicular rock faces, north or north west facing steep slopes and relatively, deep narrow valleys were over-corrected and effectively 'burnt out'. In most cases this had little impact on the accuracy of the habitat determination in these areas as limestone pavement or vegetated limestone pavement was the dominant habitat and these were mapped using the normalised difference vegetation index (NDVI).

The final habitat map (Fig. 6, reassembled in ARCGIS 8 using a raster-to-vector transformation for each habitat) was created using a variety of techniques (as described above) in an attempt to improve the level of accuracy obtained solely by a supervised classification. The methods used to classify the habitats meant that the end result was a composite of multiple images rather than a single one containing all the relevant habitats. Table 1 shows a summary of the broad habitats of the Burren identified by a combination of field work and image processing. This also shows the areas associated with each habitat in percentage cover terms.

Table 1: Broad habitats identified in the study area using satellite imagery.

Broad habitat	**Area (% cover)**	**Description**
Unimproved grassland (UG)	31%	Lower productivity, species-rich, mostly winter grazed.
• Strong 'winterage' (SW)	17%	SW: more productive, calcareous to neutral on deeper/clay soils including - wet grassland, short *Calluna* heath & some Improved Grassland on thin soils.
• Weaker 'winterage' (WW)	14%	WW: less productive, calcareous, rocky, thin soils including *Sesleria*-dominated grassland and *Dryas*-dominated heath
Improved grassland (IG)	28%	More intensively farmed - higher productivity, relatively species-poor, including 'rushy' land
Limestone pavement (LP) • Bare LP 10% • Vegetated LP 10%	20%	Ranges from bare 'massive' limestone pavement through isolated vegetated patches/bands to ~ 75% vegetated with v. thin soils
Scrub	14%	Predominantly closed hazel but also whitethorn, blackthorn and holly scrub, including ash-hazel woodland.
Calluna heath & open scrub	3.4%	These two habitats tend to overlap, but as guidance: 1) high, exposed plateaux & north-facing steep slopes tend to be *Calluna* heath with tall, mature and/or senescent *Calluna* 2) sheltered areas adjacent to existing scrub tend to be low or open scrub
Greggan's Wood shale	1.7%	Conifer plantation, blanket bog, 'rushy' grassland on shale
Water/lacustrine/turlough	1.5%	Includes water body and tall lacustrine vegetation
Dunes	0.2%	
Tillage	0.2%	Underestimated, but small

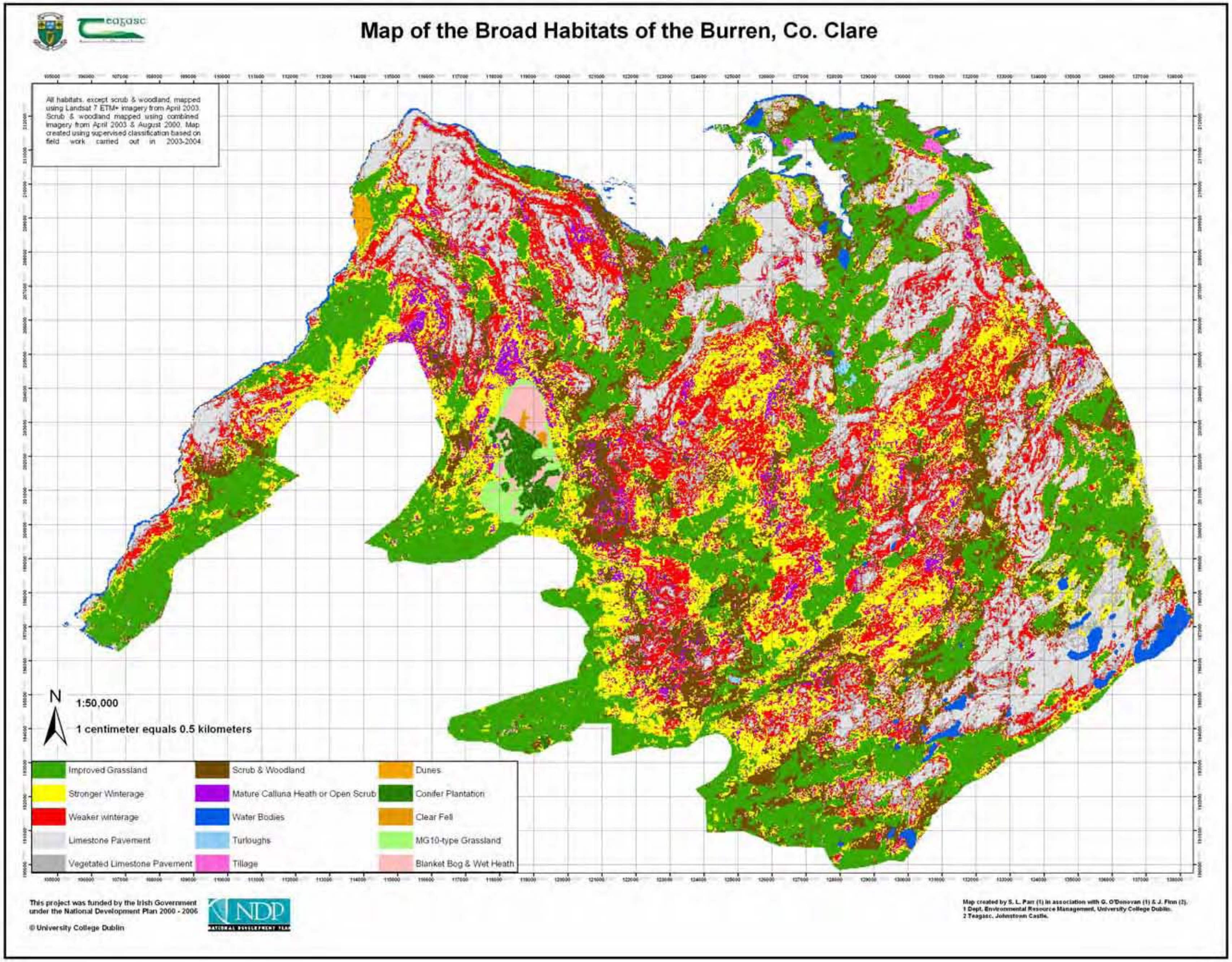

Fig. 6. Habitat map of the Burren. (Each cell represents 1km x 1km.)

DISCUSSION

This study demonstrated that Landsat 7 satellite imagery is useful for creating habitat maps of the Burren. However, while a fair representation of the broad habitat types in the Burren has been produced, it must be recognised that the habitats are more generalised than those that could be achieved by field walking and mapping methods. In addition, the map has its limitations due to: the resolution of the imagery at 30m; the complex topography of the Burren and; most importantly, the fact that habitats in the Burren do not exist within distinct boundaries (whether natural or artificial), but interdigitate in a series of complex mosaics. Using satellite imagery does, however, provide a means of mapping a large and complex area in a relatively short period of time. To map the habitats on foot would take many person-years and would not necessarily be more accurate due to the complexity of habitats and the passage of time for such a task to be completed.

In preparing the final map, a decision was made not to smooth the data to remove potentially spurious pixels, because this removed many valid pixels as well. However, when using the map it must be recognised that single or small groups of pixels representing a particular habitat may be erroneous. Conventional opinion considers that Landsat imagery is not accurate when the area of an individual parcel of a particular habitat or land cover is less than one hectare. Experience suggests that this is sometimes true and sometimes not. The resolution of the imagery at 30m means that each pixel represents an area of 30m on the ground and this pixel will be allocated to the nearest applicable habitat based on the digital number (DN) that represents its spectral value. In a perfect world, each pixel would contain only a single habitat, but the complex mosaic of habitats in the Burren means that this is certainly not the case. Hence, the classification of a pixel to a given habitat is down to the sum of its component habitats' spectral signature and as such is really only a guide to the most likely habitat to be found at that point. Another factor that one must be aware of is that the boundaries of the habitats will not concur with the actual boundaries of the habitats in reality. This is partly due to the fixed size of the pixel which means boundaries can only occur between and not within pixels. However, further boundary inaccuracies are inherent in maps produced by satellite imagery due to the 'field of view' effect and the fact that satellite images must be rectified to take in account the movement of the earth during the satellite pass over an area. Rectification was carried out using a digital elevation model (DEM) but the accuracy is limited to an extent by the resolution of the DEM and is further compromised in areas such as the Burren which have a complex topography. Therefore, it must be recognised that a given point in a satellite image does not necessarily tally exactly with it real location when plotted on a map. In terms of using the habitat map, this means that one may find oneself next to, rather than within, the habitat that you are aiming for.

CONCLUSIONS

Landsat satellite imagery does offer a means of mapping broad habitats in areas such as the Burren. Whilst providing a fair representation of the distribution and occurrence of the habitats it must be recognised that the method is not infallible and there will be discrepancies. One way of improving the accuracy of maps created using satellite imagery is to use aerial photography. While aerial photographs can be used to create habitat maps themselves, the time taken to visually inspect aerial photographs and map each habitat precludes accurate results for large areas. However, overlaying habitat classifications derived from satellite imagery onto aerial photographs can work in favour of both technologies. In the case of the classified satellite image, it allows rapid assessment of the accuracy of the classification which enables corrections to be made, thus improving the accuracy of the result. In the case of aerial photography, it facilitates a faster visual interpretation as the human eye can focus on particular classifications and make the habitats easier to detect.

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