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The potential of LANDSAT Thematic Mapper satellite imagery as a tool for assessing degradation of blanket bog and wet heath

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Abstract
Within the context of the EU Habitats Directive, Dúchas (National Parks and Wildlife) is obliged to ensure favourable conservation status of designated habitats within those areas that it has forwarded for inclusion in the EU Natura 2000 network. In 1999, Dúchas funded a number of studies to determine whether satellite imagery could be used as a tool in its SAC monitoring programme. The Owenduff/Nephin candidate SAC in County Mayo was selected as one of a number of test sites to determine whether LANDSAT imagery could be used to identify different grades of degradation on blanket bog and wet heath habitats due to overstocking by sheep. This has been established as the causal mechanism for this degradation via a grazing condition assessment field survey jointly carried out by the Department of Agriculture, Food and Forestry (DAFF) and Dúchas. Based upon the methodologies that were employed within similar studies, unsupervised classification was used to subdivide a LANDSAT image of the area into 20 spectrally defined land-cover classes. Field survey revealed that many of these spectral classes coincided with the distribution of identifiable habitats and land-cover classes. These were subsequently outlined as twelve semi-natural vegetation classes, five agricultural/agri-industrial land-cover classes, and three ambiguous land-cover classes that corresponded with more than one land-cover type. Eight of the twelve semi-natural vegetation classes were characterised by varying degrees of peat exposure, suggesting that LANDSAT imagery can be used to highlight levels of degradation on blanket bog and wet heath.

Introduction

As a consequence of their monitoring obligations, as outlined within the Habitats Directive (92/43/EEC), Dúchas are developing methods for monitoring the ecological status of the 700,000 hectares (Dúchas, 1996a) of candidate Special Areas of Conservation (cSACs) which must be maintained, or restored to, favourable conservation status. One of the approaches that they are evaluating is the potential use of satellite imagery to assess and quantify physical change and reduction or loss of vegetation cover. Previous studies have demonstrated that satellite imagery can be used as a tool for broad-scale habitat monitoring in large semi-natural areas (Cooper and Loftus, 1997; Wright *et al.*, 1997; Yool *et al.*, 1997; Reid *et al.*, 1994; Blasco and Archard, 1990; Bunce, 1989, Betts *et al.*, 1986), but none have used satellite imagery to detect reduction of vegetation cover by degradation.

A significant proportion of the cSACs for which Dúchas is responsible are in uplands or blanket bog areas (Foss and O'Connell, 1996) and one of the chief environmental problems in these areas is overstocking-related soil erosion (Bleasdale, 1998). This study was commissioned to determine whether LANDSAT satellite imagery could be used as a tool for identifying the impact of overstocking in these areas and monitoring recovery in the future. Since the problem is particularly severe in the west of Ireland, three post-graduate studies focused on three large cSACs in that area. These were the Owenduff/Nephin, Mweelrea/Sheefry/Erris complexes in county Mayo and the Connemara Bog Complex in county Galway. This study covers the Owenduff/Nephin cSAC Complex.

Recent research suggests that contemporary erosion in western counties is related primarily to overstocking with sheep (Bleasdale, 1998, 1995; Weir, 1996; Bleasdale and Sheehy-Skeffington, 1991). Blanket bog vegetation has a low nutrient content, so the sheep that graze upon it must range extensively in order to meet their nutritional requirements (Grant *et al.*, 1985; Rawes, 1981; Grant *et al.,* 1976). As a consequence of the soft peat substrate and the relatively fragile surface vegetation cover, blanket bogs are naturally vulnerable to damage by overstocking. The high rainfall amounts that are required in order for blanket bog to develop (Collins and Cummins, 1996) become a strongly erosive force once the surface layer of vegetation has been removed (Brady, 1990). Since much of the west is characterised by thin mineral soils (Sleeman, 1992; Bowen, 1977) there is little opportunity for plant regeneration to occur once the overlying peat has been eroded.

The intrinsic sensitivity of blanket bog to overstocking has not been taken into consideration in land use policy. The introduction of EEC product support measures for sheep meat in 1980 resulted in a doubling of the national herd by the early 1990s (O'Riordan, 1996) and this caused severe degradation in sensitive areas. The introduction of the Rural Environmental Protection Scheme (REPS) in 1994 did finally stabilise sheep numbers nationally, but overstocking of western blanket bogs and upland areas is still a real problem (Bleasale, 1998). The Owenduff/Nephin cSAC is typical in this respect, with significant portions of the area showing different degrees of integrity from intact to severely degraded. It is for this reason that it was selected as a suitable site within which to test the effectiveness of satellite imagery as a tool for detecting degradation.

Satellite imaging is a potentially useful tool in environmental monitoring because it enables one to obtain quantitative data about large and otherwise inaccessible areas by remote means. This data usually consists of digitally recorded information regarding the characteristic manner in which individual surfaces absorb, scatter and reflect the incident electromagnetic energy of the sun. The human eye senses some of these differences as visible colour, shade and texture, but the sensors of Earth Observation satellites such as the LANDSAT series can sense in the near-infrared, mid-infrared and thermal infrared wavelengths. The sensing capabilities of these instruments makes it possible to classify features on the earth's surface to a much higher level of interpretation than would otherwise be possible. The instruments onboard the LANDSAT series of satellites are optimised to study and classify vegetation in particular.

Photosynthesising plants reflect visible electromagnetic energy in similar ways (i.e. healthy plants all appear green to the human eye). However, plants reflect an even greater amount of electromagnetic energy in the near-infrared wavelengths, and the unique ways in which different plant species reflect near-infrared enables species stands to be identified from satellite imagery. It is the correspondence of (almost) unique near-infrared signatures with individual species stands that makes land-cover mapping from satellite a possibility (Lillesand and Kiefer, 1994).

Many studies have assessed the suitability of Landsat Thematic Mapper (TM) imagery as a tool for the inventory of peatland resources. Reid *et al.* (1993) used LANDSAT TM imagery to highlight and assess ecological variation within areas of blanket bog in northwestern England and eastern Wales. They applied Principal Components Analysis to an unsupervised classification of their chosen area in order to separate peatland from non-peatland areas, identifying six distinct peatland habitat/vegetation classes, the ground-truthing of which produced an accuracy of approximately 75%. Wright *et al.* (1997) used TM imagery and digitally enhanced aerial photographs to inform an unsupervised classification of a 50km^2 area of peatland in Scotland. They isolated four habitat/vegetation classes within their study area and went on to use this information in conjunction with a computer model to calculate suitable potential sheep-stocking rates in a range of management situations (Wright *et al.* 1997). In a more recent study, Boresjö Bronge (1998) used a combination of TM imagery and aerial photographs to isolate nine distinct peatland habitat/vegetation classes in a peatland area in Sweden, and this information was used to inform The Swedish Land Survey land-cover mapping programme. None of these studies explicitly investigated whether it was possible to highlight or classify degradation in peatland areas. Tomlinson (1981) did successfully map and classify water erosion features in the uplands of Northern Ireland, but he was not concerned with causes. Thomson and Milner (1989) did examine LANDSAT TM imagery of North Wales in an attempt to correlate the reflectance characteristics of peatland vegetation with sheep numbers, and their work did suggest a link between grazing and vegetational change, but they did not attempt to classify grades of degradation. Paracchini *et al.* (1998) did use LANDSAT TM imagery to directly identify soil erosion patterns, but their assessment was limited to a non-peatland area.

Some land-cover identification work has been done in the Mayo area (Krause-Rabe, 1986), and one has even focused on the Owenduff/Nephin cSAC itself (Weir, 1996). However, Krause-Rabe was concerned with the identification of peatland vegetation categories (identifying three human-influenced bog vegetation categories and one natural bog category) and Weir assessed the 20 year progression of overstocking-related exposure of bare rock within the Owenduff/Nephin cSAC from aerial photographs. Unfortunately however, Weir found that aerial photography was not well suited to the identification of grades of erosion damage.

Methods

Data

The primary data source that was used in this survey was a cloud-free, April/May 1997, 30 X 30-metre pixel-resolution, seven-band, rectified LANDSAT 5 TM image of the Mayo area (path number 208, row 22).

Other data sources included:

a) A vector coverage (ARCINFO format) of the boundary of the Owenduff/Nephin cSAC (courtesy of Dúchas monitoring staff).

b) A list of the habitats that have been identified by Dúchas monitoring personnel within the cSAC (Dúchas, 1994).

c) The most recent commonage-zoning map for the Owenduff/Nephin complex, which outlines grazing damage in the complex as assessed by Dúchas staff in the field (Dúchas, 1994).

d) A Habitat map (Natura 2000 version) of the Owenduff/Nephin complex (Dúchas, 1994).

e) Ordnance survey (O.S.) 1:50,000-scale Discovery maps (numbers 22, 23, 30, and 31) of the Mayo area.

Image classification

Many studies (Wright *et al.* 1997; Reid *et al.* 1993; Belward *et al.* 1990; Wardley *et al.* 1987 and Driscoll *et al.* 1974) have used unsupervised classification to classify peatland land-cover. Following on from this, an unsupervised classification was performed on the LANDSAT image of the Owenduff/Nephin area to highlight variations in the semi-natural vegetation within the cSAC. Image classification was conducted in Erdas Imagine 8.3.1.

Unsupervised classification uses an ISODATA (Iterative Self-Organising Data Analysis Technique) algorithm to cluster spectrally similar pixels into spatially defined groupings that correspond with features on the earth's surface. Classification was conducted on a waveband combination that highlights vegetation characteristics effectively.

The process of image classification involved the following steps:

1. The unclassified LANDSAT TM image was displayed in Erdas Imagine in band 4,5,3 format using red, green, blue (respectively) for the false-colour composite.
2. The TM image was edge-enhanced in Erdas to aid visual discrimination of the land-cover prior to image classification.
3. The vector boundary of the Owenduff/Nephin cSAC was imported into Erdas (from Unix Arcinfo) and superimposed as a vector layer over the unclassified image.
4. A rectangular area of interest (encompassing the cSAC) was selected on-screen to define the area to be classified.
5. The unsupervised classification was set to delineate 20 spectral classes. Twenty classes were judged sufficient to allow for the sum of land-cover types that were readily recognisable, including a number of habitat and grazing level classes.
6. Erdas was set to continue to automatically re-classify the image until 95% of the pixels remained unchanged from one re-classification to the next (setting the limit above this level results in diminishing returns in terms of processing time as a function of increases in image classification accuracy).
7. Image classification was set to cluster 30 X 30-metre TM-image pixels into 60 X 60-metre classified-image pixels in order to simplify land-cover identification in the field.
8. Unsupervised ISODATA classification was started, and the results were saved to a separate image file for analysis.

Classified-image enhancement

A high-contrast version of the unsupervised classification was generated by manually assigning easily distinguished colours to all classes in order to aid land-cover identification in the field. Groupings of associated colours were used where initial image interpretation suggested the existence of related classes. A laminated hard copy of this image was used (in conjunction with O.S. Discovery maps and a non-differential

Global Positioning System (GPS) receiver) to locate sample areas of unknown land-cover for identification in the field.

Field survey

The aim of the fieldwork was to attach ecological characteristics to each of the unidentified spectral classes that were highlighted during image classification. Ground survey stations, e.g. a 60m² area, were sited in the middle of the largest spectrally homogenous areas that could be accessed accurately on the ground. Due to time limitations, only one example of each unidentified spectral class was visited in the field. A modified assessment-card was compiled from the general field and station report cards used by Dúchas in grazing condition assessment (Dúchas, 1998). This was used to record details of broad habitat type (as indicated by soil type and depth), percentage vegetation cover, vegetation height, percentage bare peat, peat-erosion type, commonage land-use activities and principle plant species encountered throughout the sample site.

Class assignation

The data gathered on site were used to assign land-cover classes to the unsupervised classification. Spectral classes were then assigned names based upon the ecological characteristics that were identified at the relevant field stations and an array of new images was generated in Erdas Imagine to categorise land-cover classes into logical groupings.

Map generation

Classes were overlaid on a background LANDSAT image of the Owenduff/Nephin cSAC and its vector boundary. These maps were designed to highlight overstocking damage and habitat/vegetation zonations within the bounds of the cSAC. Only the degradation map is presented in this study.

Results

The results fell into three main categories:

1. An unsupervised classification of the LANDSAT image of the cSAC (Fig. 1).
2. The land-cover characteristics of the unknown spectral classes as identified in the field (Table 1).
3. Landsat classes showing habitats affected by overstocking as informed by the field survey results (Figs. 2 and 3).

Image classification

A 20-class unsupervised classification image of the Owenduff/Nephin complex highlighted the spectral variations on the image that coincided with 20 distinctive land-cover classes within the cSAC. Six land-cover classes were readily recognisable before fieldwork began and fourteen were not. Since it was difficult to visually discriminate between many of the unknown land-cover classes on the initial unsupervised classification image prior to field assessment, highly contrasting colours were applied to all classes to aid in their identification in the field (Figure 1).

Field assessment

The information that was gathered regarding the ecological attributes of the unknown ground-cover classes (Table 1) facilitated the production of land-cover maps of the area.

Assignation of ground-characteristics to the classified image

The assignation of ground-truthed ecological characteristics to unknown spectral classes indicated that different spectral signatures corresponded with individual land-cover types. Mapping individual or logically grouped land-cover classes (within Erdas) highlighted the geographical distributions of these land-cover

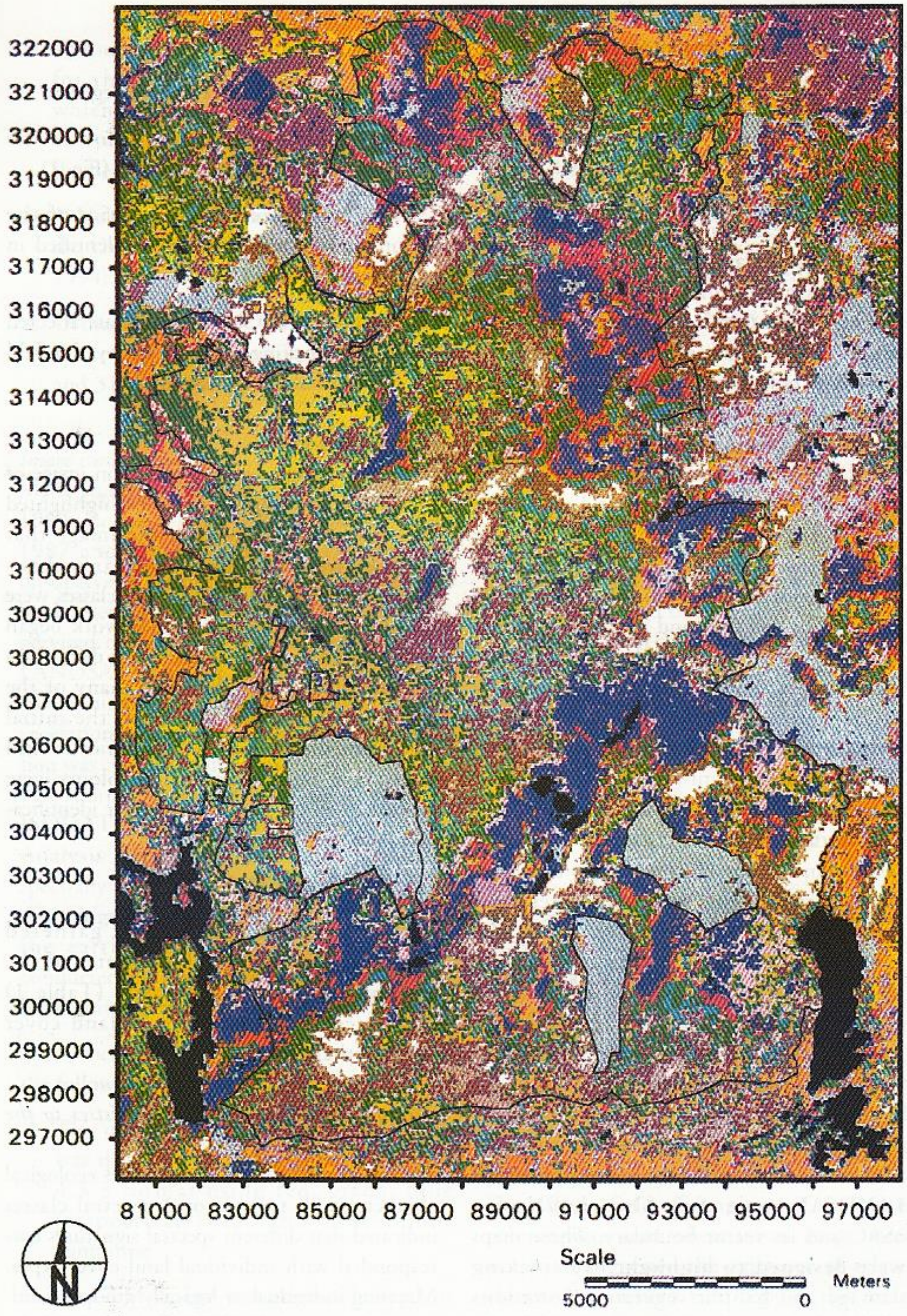

Figure 1: High-contrast unsupervised classification of the Owenduff/Nephin complex.

Legend for Figure 1

Class_Names

- Water and topographical shadow mix.
- Mature coniferous forest.
- Eroded upland blanket bog (75% bare peat).
- Clear-felled and immature coniferous forest mix.
- Industrially cut bog.
- Eroded upland blanket bog (60% bare peat).
- Unidentified but eroded upland** (% bare peat not identified) and sparse conifer mix.
- Eroded wet heath on sloping ground (50% bare peat).
- Grazed scrub on wet heath (85% bracken and 65% understorey of heather)
- Improved grassland.
- Semi-improved grassland.
- Degraded lowland blanket bog*, 70% mixed grasses, relatively dry.
- Lowland blanket bog** (possibly intermediate wetness).
- Apparently intact lowland blanket bog*, 85% Purple Moor grass, relatively wet.
- Overgrazed heath, 30-40% bare peat.
- Grassy wet heath (with 10% scree presence).
- Severely overgrazed heath, 40% heather, 40% bare peat.
- Slope-related brightness and unclassified coniferous forest class mix.
- SAC boundary

classes on the ground. Some of the general patterns that emerged from this process were:

1. The uplands in the south, southeast and the eastern portions of the cSAC displayed spectral signatures that corresponded with three distinct grades of very severe peat-erosion as surveyed on the ground. Unsupervised classification appears to have differentiated between upland blanket bog with 75% bare peat and upland blanket bog with 60% bare peat (Fig. 2) as well as identifying wet heath with 50% bare peat (Fig. 3).

2. Significant portions of the hill-slopes in the southern, central and north-central sectors of the cSAC appear to correspond with areas of degraded heath. Two grades of overstocking damage were identified, represented by 40 % bare peat and 30% bare peat respectively.

3. A significant proportion of the western lowlands of the cSAC appears to be covered with damaged blanket bog with approximately 20% bare peat.

4. Further classes that were identified in the field using the grazing condition assessment cards (for which maps are not included) were:

   - Seriously degraded due to overstocking (approximately 10% sub-canopy bare peat) bracken and heather canopy on wet heath.
   - Moderately grazed grassy heath (evidence of grazing but 0% bare peat).
   - Apparently intact blanket bog.

5. Five agricultural/agri-industrial land-cover classes were also identified within the cSAC. These classes were:

   - Mature coniferous forest.
   - Clear-felled and/or immature coniferous forest.
   - Industrially cut bog.
   - Improved grassland.
   - Semi-improved grassland.

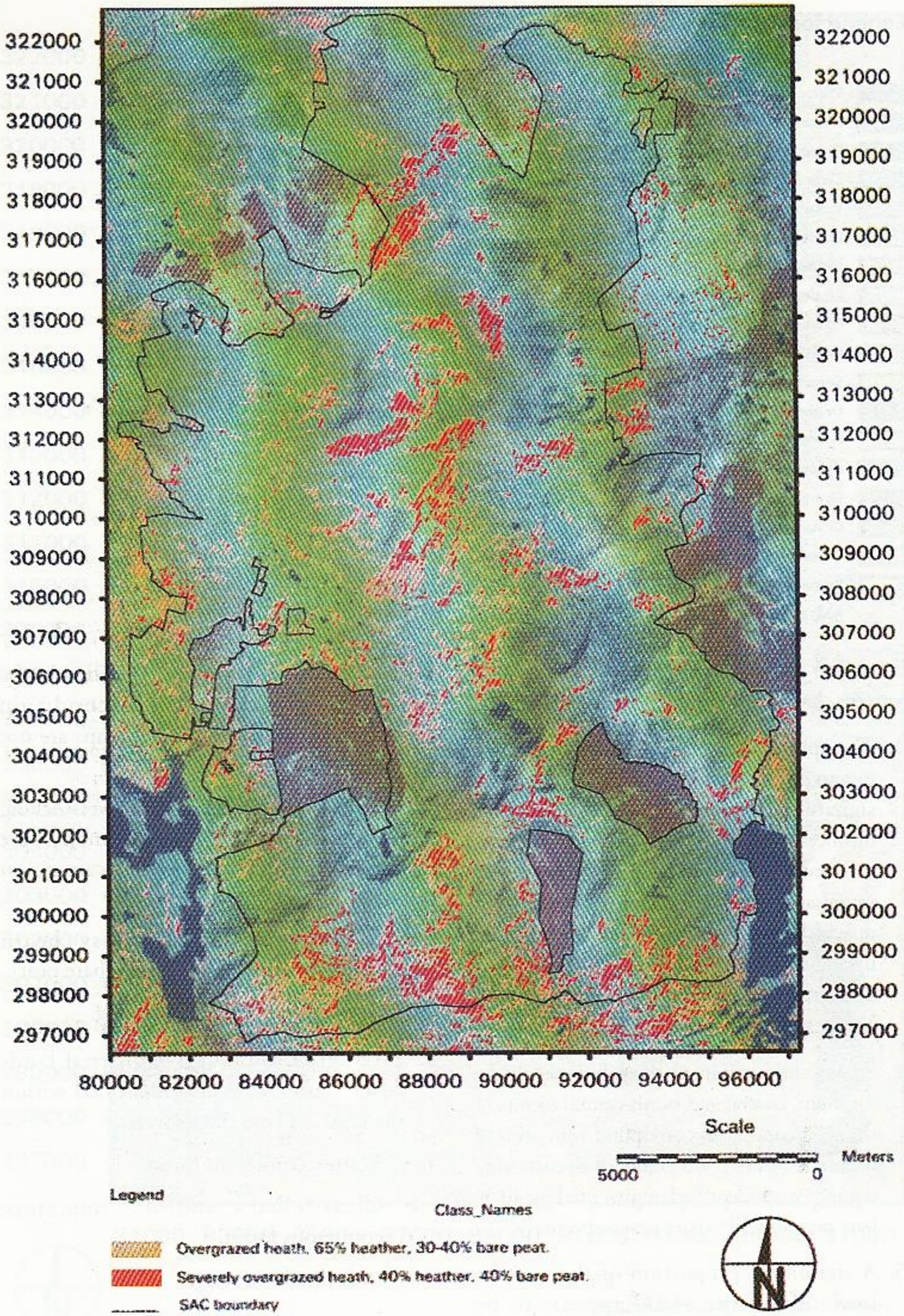

Figure 2: Types of heath degredation in the Owenduff/Nephin complex.

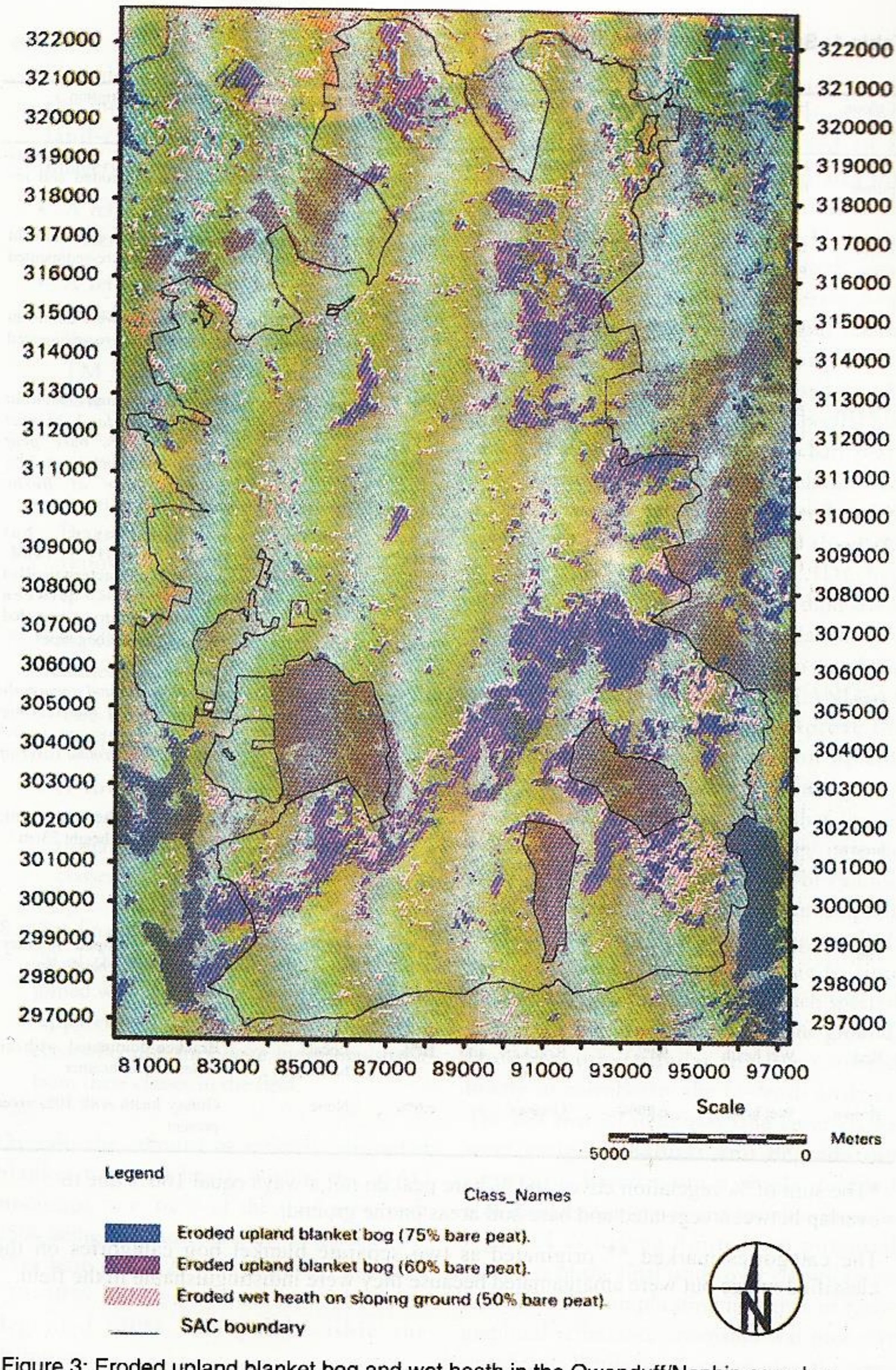

Figure 3: Eroded upland blanket bog and wet heath in the Owenduff/Nephin complex.

Table 1: Summary data from the field survey

Colour class.	Habitat type	% veg. Cover*	Dominant veg. Type	% bare peat*	Erosion type	Qualitative description
Dark purple	Upland blanket bog	c.50%	Purple Moor grass	c.75%	Sheet and gully erosion	Purple Moor grass was dominant on eroded and re-sedimented peat
Purple	Upland blanket bog	c.60%	Mixed grasses	c.60%	Sheet and gully erosion	Mixed grasses were dominant on eroded and re-sedimented peat
Pink	Wet heath	50%	Mixed grasses (no heather)	50%	Sheet and gully erosion	Mixed grasses were dominant on eroded and re-sedimented peat
*****Deep green***	*Blanket bog (peat depth >80cm)*	*100%*	*Grasses Bushy lichens Heather*	*20%*	*None*	*Relatively dry and somewhat degraded lowland blanket bog with 20% bare peat between hummocks with 20% ground cover of Bushy lichens.*
Yellow	Blanket bog (peat depth >80cm)	No survey	Grasses	No survey	No survey	Not surveyed but geographically (and possibly characteristically) transitional between wet/intact and dryer/degraded lowland blanket bog types.
*****Blue***	*Blanket bog (peat depth >80cm)*	*100%*	*Grass Heather Peat mosses*	*0%*	*None*	*Relatively wet and apparently intact lowland blanket bog with 50cm average sward height a 20% ground cover of heather.*
Reddish brown	Wet heath (peat depth 15-80 cm)	c.90%	Heather Grasses Peat mosses Bushy lichens	c.30%	Patchy blackspots	Bushy heather present. Average sward height 23cm
Tan	Wet heath (peat depth 15-80 cm)	c.70%	Severely truncated Heather and Grasses.	c.40%	Patchy mosaic	Severely cropped heather. Average sward height 9cm
Red	Wet heath	90%	Bracken and Heather	10%	Local blackspots	Bracken-dominated with an understory of heather.
Brown	Wet heath	c.90%	Grasses	c.0%	None	Grassy heath with 10% scree present

*The sum of % vegetation cover and % bare peat do not always equal 100% due to overlap between vegetated and bare-soil areas on the ground.

The categories marked ** originated as two separate blanket bog categories on the classified image but were amalgamated because they were indistinguishable in the field.

6. Three ambiguous land-cover classes were also identified, demonstrating some of the inherent difficulties of classifying land-cover from LANDSAT TM imagery. These included:
   - A reflectance class overlap representing water and heavy topographical shadow.
   - A reflectance class overlap representing undefined background land-cover classes that appeared bright on the unclassified TM scene. (These surfaces appear to have included sunlit south-facing slopes and undefined light-coloured surfaces elsewhere within the cSAC).
   - A reflectance class overlap represented by an unsurveyed upland erosion class (known by Dúchas personnel) and a sparse conifer plantation class.
7. Two classes were not surveyed. These included:
   - The unsurveyed upland erosion class mentioned above.
   - A lowland blanket bog class that appeared to be geographically transitional between lowland blanket bog classes that were surveyed.
8. The final two classes (making up the initial 20 of the unsupervised classification) were joined with the 'bare peat affected' and the 'apparently intact' lowland blanket bog classes because they were indistinguishable from these classes in the field.

Overall, the amount of seriously degraded blanket bog and heath within the cSAC amounted to c. 60% of the total area, with 25% being the most seriously degraded (50-75% bare peat), 20% moderately degraded (30-40% bare peat) and 15% the least degraded (20% bare peat) within the definition.

Discussion

Similar to previous studies (Wright *et al.*, 1997; Reid *et al.*, 1993), unsupervised classification of a TM image proved to be successful in dividing a peatland area into spectral classes that reflected variations in the semi-natural land-cover in the field. In this instance however, the same approach seems to have isolated grades of overstocking damage across a variety of peatland habitat types (Figs. 2 and 3). Of the original 14 land-cover classes (later rationalised to 12), seven seem to have reflected the spectral bias of severe peat erosion (75% - 20% bare peat). The locations of these degraded classes were found to correspond with the general pattern of peat erosion as outlined on the 1998 Natura 2000 map of the cSAC (Dúchas, 1994). Crucially however, this method seems to have classified habitat degradation to a much higher level of detail than has been possible to date, suggesting that LANDSAT TM imagery can be used to improve the identification of peat erosion on upland blanket bog and wet heath in Ireland.

There are a number of issues that should be considered if this methodology is to be developed further. Firstly, a note of caution should be sounded in relation to the sampling methods that were employed during the field-survey phase of the project. Due to time limitations, only one example of each spectral class was visited and surveyed on the ground. However, other similar sites were visited briefly to corroborate the in-depth analyses. The fact that all unknown land-cover classes were assigned habitat and degradation signatures based upon a single detailed ecological assessment at one location must be regarded as having limited the potential reliability of the final land-cover classification. Secondly, the complicating influence of topographical reflectance anomalies was probably significant. While the discovery that the most severe erosion was to be found in the upland portions of the cSAC corresponds with the experience of Dúchas personnel, some of the upland portions of the TM image were also characterised by alternate areas of deep shadow and strong solar reflection. Solar angle can be artificially altered (within Erdas) to compensate for these problems, and any future work will undoubtedly benefit from a consideration of this issue. Thirdly, while the differentiation of degrees of vegetation denudation and peat exposure was a useful outcome, it is not tested to what extent unsupervised classification will detect the percentages of bare peat (1% - 10%) that have been set by Dúchas and the Department of Agriculture, Food and Forestry (1998) as indicators of serious degradation and linked to specific stock reductions in the Owenduff cSAC. There may be a role for supervised classification in this regard, but this method does require more substantial fieldwork, and the varied nature of the vegetation in peatland areas does tend to make it unsuitable (Wright, *et al.*, 1997; Reid *et al.*, 1993; Belward *et al.*, 1990; Wardley *et al.*, 1987). While it may seem that reducing the pixel size of the initial image and its classified output would enable one to detect lower percentages of bare peat, there are at least two reasons why this is unlikely to be the case. The spectral characteristics of pixels within digital satellite images constitute averages of the areas that they represent on the ground-surface (Lillesand and Kiefer, 1994). Therefore, image pixels tend to represent the largest and the brightest features on the earth's surface. The more one wishes to infer the influence on image pixels, of features that have a low percentage ground-cover, the less will be their spectral influence on the pixel average. Also, Townshend (1983) found that increasing pixel resolution can reduce classification accuracy because it tends to sub-divide the ground-cover into a level of detail that is not easily interpreted.

In general however, the interpretation of LANDSAT TM imagery appears to offer real opportunities for Dúchas with regard to improving the identification and quantification of peat erosion and habitat/vegetation zones within blanket peat and heath dominated cSACs. Significantly, it seems to offer a relatively rapid and reliable means of classifying large and otherwise inaccessible areas on regular basis. More work needs to be done however to determine its fullest potential and to establish its limits in the identification of peatland habitat degradation, whatever its cause.

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