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Rapid Assessment Protocol for the Monitoring of Burning in *Calluna* Dominated Environments

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ABSTRACT

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Rapid Assessment Protocol for the Monitoring of Burning in *Calluna* Dominated Environments

The controlled burning of heather has been a management technique for red grouse since 1850. Whilst it is known to benefit other vegetation, birds and invertebrates, a recent review has outlined potential damages caused by the practice, and there is concern that management practices have intensified. There is a lack of quantitative information regarding the extent of burning practices, on which changes in practice and ecological impacts can be investigated. Information on burning practices at national, regional and local levels is required.

The aim of this work was to develop a tool that is suited to the rapid estimate of the scale of burning and allow the generation of such information. A GIS tool was developed to apply a point sample methodology and manual interpretation of aerial photography to assess the scale of burning at landscape level. The tool enabled assessment to be made four times faster than conventional methods of digitising, and was shown to estimate areas to an accuracy of 94%. The mapping product offers information on the scale of burning suitable for a landscape level assessment, and could be applied to local level assessments such as estates or catchments.

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GLOSSARY OF ABBREVIATIONS

BANCIK
Bulgarian land cover/land use survey based on area frame sampling.

ECW
Enhanced Compressed Wavelet is a compression technology developed by Earth Resource Mapping that enables the file size of digital imagery to be reduced by a compression ratio of up to 50:1, while retaining high quality.

MFTF
Moors for the Future is a partnership project to restore large parts of the internationally important Peak District moors. The partners are The Peak District National Park Authority, United Utilities, English Nature, National Trust, Yorkshire Water, Severn Trent Water, Sheffield City Council, DEFRA, Peak Park Moorland Owners & Tenants Association, Country Land and Business Association and National Farmers Union.

LUCAS
Land Use/Cover Area Frame Statistical Survey carried out by EUROSTAT, collecting data on land use/cover, agricultural practices and environmental features at approximately 100000 observation points across the EU.

LCM2000
Land Cover Map 2000 is a map of Great Britain produced by the Centre for Ecology & Hydrology that was derived from vector-based classification of Landsat satellite scenes.

TERUTI
French land cover/land use survey based on area frame sampling.

VBA
Microsoft's Visual Basic for Applications is the development environment and language found in Visual Basic that can be hosted by applications

WAAS
The Wide Area Augmentation System consists of a series of differential GPS ground stations that broadcast correction information to GPS receivers, allowing them to achieve a more accurate position determination.

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INTRODUCTION

Controlled burning on heather moorland to create mosaics of differing-aged stands of heather is a management technique for red grouse *Lagopus lagopus* that probably dates to 1850 (Lovat 1911, cited in MacDonald, 1999). Overall Bardgett *et al*. (1995) found heather in better condition in England and Wales where large areas of moorland are managed in this way. Thomas *et al.* (2004) indicate that over 27% of *Calluna* dominated environments in the English Uplands show evidence of recent heather burning. Although carefully managed burning plays an important role in the maintenance of open semi-natural upland habitats and benefits a number of other birds (Tharme *et al.*, 2001) and invertebrates (Gardner & Usher, 1989, Usher, 1992), English Nature have shown concern regarding potential damaging impacts on vegetation, birds, soils and hydrological processes. Tucker (2003) outlined these in a recent review of burning in the uplands, and also noted that field observations have indicated that management practices, including the frequency of burning rotations, have intensified on some grouse moors. Too frequent burning can reduce the dominance of *Calluna* (Hobbs & Gimingham, 1987), and regeneration following the burning of *Calluna* stands that have been out of management for many years is often reliant on seed germination. This allows greater opportunity for erosion and colonisation by other species (Hobbs & Gimingham, 1984). Inappropriate moor burning was found to be the second most extensive cause of unfavourable condition on upland Sites of Specific Scientific Interest (SSSI) in England (English Nature, 2003).

Quantitative information on the current and historic extent of burning practice within the English Uplands, on which changes in practices and ecological impacts could be investigated, is lacking (Tucker, 2003). A recent study on a 2% national sample of the uplands (Thomas *et al*., 2004) found no overall change in the level of management since the 1970s, but linked the recent introduction of mechanical methods with localised areas of increased activity. There is evidently a need to generate information on burning practices at national (e.g. the English Uplands), regional (e.g. National Parks) and local levels (e.g. individual estates or catchments). How that level of information is achieved is dependant on a range of factors, including the organisation producing the information, its intended use and the required accuracy. The options are largely a function of the source data (e.g. aerial photographs, satellite imagery) and the methods of interpretation (e.g. visual interpretation combined with manual digitising, automated classification of pixels and/or sub-pixels).

The repeated coverage of satellite imagery and automated digital classification perhaps offer such a solution, but despite the pattern of burning being visible on upland areas in the Land Cover Map 2000 (LCM2000) derived from 30 m Landsat imagery, areas of heath and moor are over-represented (Fuller et al., 2002). The discrimination of these patterns is also simply burnt or not burnt. Other research by Bird *et al*. (2000), in the Monitoring Landscape Change in the National Parks (MLCNP) project, showed that confusion arose within moorland sub-classes using 20 m SPOT imagery. Thomas *et al*. (2004) demonstrate that a resolution of 5 m is required to provide an adequate basis for mapping recent patterns of burning practice, and that it is possible to obtain information on the relative ages of burns from 25 cm resolution colour aerial photography.

Since aerial photography is traditionally interpreted manually, with area estimates being produced using hand-drawn (Ward *et al*., 1972, Taylor *et al*., 2000) or digitised (Thomas *et al*., 2004) polygons, the process is inherently slow. Segmentation using object-based classifiers has been used to improve the speed of mapping landscape features (e.g. LCM2000) and burned areas of forest (Mitri & Gitas, 2004), but there is no information in the literature on the use of such processes to interpret heather burning in aerial photography. Due to the geographic and seasonal variations in vegetation across the uplands, manual interpretation is likely to provide more consistent classifications, and will also enable immediate analysis of historic photography which is not radiometrically corrected. An alternative to digitised polygons is point observations, an approach that has been used to detect national land cover/land use changes (e.g. TERUTI, BANCIK and LUCAS).

The Moors for the Future Partnership (MFTF) are currently undertaking research in the Peak District National Park (PDNP) into the effect of burning on birds, vegetation, invertebrates and peatland dynamics. Information on the scale of burning at landscape level is of key interest in their work. English Nature has greater requirement for this information at estate or catchment level. Neither party has access to advanced image processing facilities, but do have a catalogue of aerial photography. The aim of this project is to develop a tool suited to rapid estimates of the scale of burning that retains the qualities of visual interpretation and allows some level of mapping. This paper presents the design of a point sampling strategy to be used on 1 km squares and the development of a GIS software tool to apply such a sample to assess the landscape scale of burning from aerial photography. The research included analysis of:

- the sample design;
- the area estimation accuracy achievable for a range of sample point densities;
- aerial photograph interpretation for discriminating burn scars;
- digitisation compared to the point sample protocol;
- the level at which the tool can be applied, including the PDNP.

METHODS

Calluna classification

The scale of burning is a reflection of the proportion of the area that is burnt, but the entire extent of *Calluna* dominated moorland is likely to have been burnt at some point, due to the long history of the management technique. Therefore if a relative age of burning can be assigned to the stage of *Calluna* regeneration, a scale of burning in the area can be deduced from the proportion of *Calluna* in each stage. Four age classes of *Calluna* respective to burn were identified from colour aerial photography by Thomas *et al*. (2004) and are summarized in Table 1.

Table 1. Classification of *Calluna* re-growth, and visual characteristics in colour aerial photography (after Thomas *et al*., 2004).

Class	Relative age of burn	Identification	Visual characteristics in aerial photography
1	New	Open, sparse or nonexistent *Calluna* canopy	Usually much lighter in colour than surrounding *Calluna*
2	Recent	Partial and closing canopy	Darker patches of regenerating *Calluna*
3	Mid-aged	Dense, closed canopy	Dark and visibly smooth canopy
4	Old	Uneven, opening canopy	Canopy slightly lighter than 3, with a ‘lumpy’ texture

It is not possible to assign actual ages of burn to these classes, due to the varied response of *Calluna* following burning. However, based on the age brackets of the pioneer, building, mature and degenerate growth phases of *Calluna* suggested by Gimingham (1959), Thomas *et al*. (2004), suggest that classes could represent the approximate ages in Table 2. Examples of the appearance of each class in colour aerial photography are provided in Appendix B.

Table 2. Approximate age of classes of *Calluna* regeneration (after Thomas *et al*., 2004).

Class	Approximate age
1	Up to 5 or 6 years
2	4 to 12 years
3	10 to 25 years
4	22+ years

Sampling design

A systematic aligned grid was chosen to give representative and proportional cover of the full square kilometre, and will in time enable burn return period information to be derived for the same geographic locations. Since there is no relation between the location of the OS grid and the underlying landscape, it was reasoned that the position of a start point did not need to be randomly generated. Preliminary analysis was conducted to assess how accurately the area of burn scars can be determined for different sample point densities. The burn scars used in the analysis were previously digitised from aerial photography of the uplands (see Thomas *et al*. (2004) for description of digitisation methods). The original extent of the burn, from which the *Calluna* was regenerating, was still visible for classes 1 to 3 when digitised, and therefore these three classes were selected for analysis as they represent true burn size and distribution. Ninety-seven 1 km squares of digitised burns (Figure 1) were analysed.

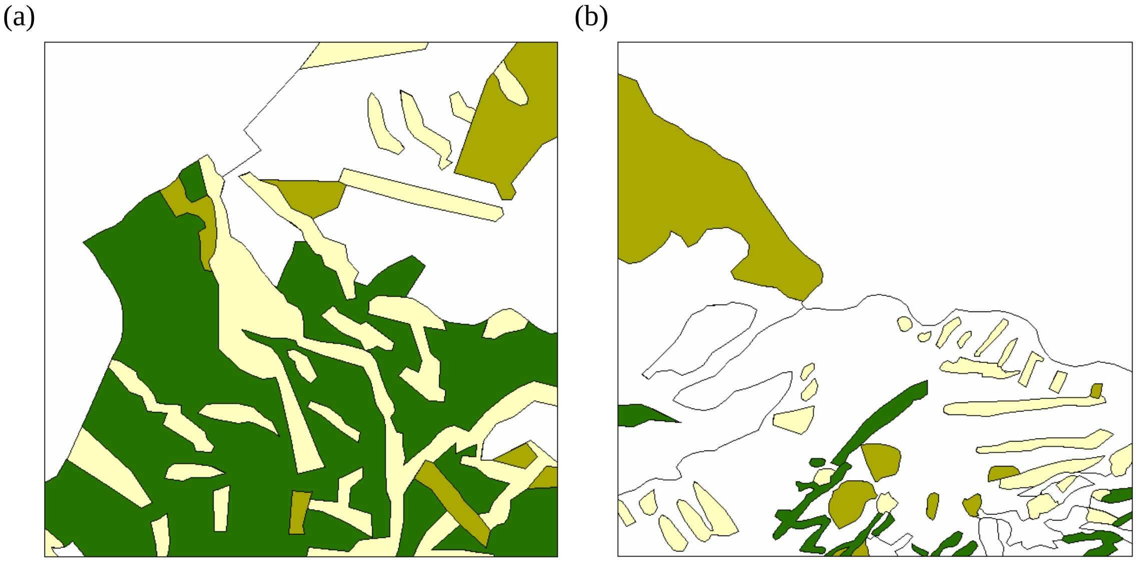

Figure 1. Examples of digitised burn scars, classified in terms of *Calluna* regeneration following burning; (a) OS grid square SD9958, (b) OS grid square NY6641. Classes; 1, 2, 3.

The analysis was based on sample point densities relating to grid spacings of 100m, 75m, 50m, 25m, 10m and 5m. A GIS tool was developed to semi-automate the creation of these predefined grid sizes, and count the number of points falling in each polygon (see Appendix A). The total area of each class of *Calluna* (by square) was estimated using the proportion of points that fell within polygons of that class. To assess sampling accuracy, the error of the estimated area of each class within each square was expressed as a proportion of the true area of that class. The mean proportionate error (MPE) of these estimations was then calculated for each grid size.

A target accuracy of 95% had been set by MFTF, and the grid spacing required to achieve this level was calculated. The effect of the location of the points on the area estimations was investigated by moving the grid a random amount in four directions, whilst ensuring that all the points still fell within the 1 km square. A t-test analysis was performed to evaluate whether the differences were significant. Further analysis was then conducted on the relationship between the area of each class (by square) and the accuracy of the area estimation, and also between the actual area of individual polygons and the respective estimate accuracy.

Development of rapid assessment protocol

ECW compressed digital, orthorectified 25 cm resolution colour aerial photography for the PDNP, captured by UK Perspectives between 1999 and 2003, was provided by MFTF. Magnification of the photography was required to discriminate and interpret the class of *Calluna*. As this was found to be image specific, a defined magnification was excluded from the protocol.

Initially, the GIS tool was designed to allow classification on a point-by-point basis. Creation of the sample grid was again a semi-automated function. The tool centres the image on the point to be classified, and provides a predefined list from which the appropriate class can be selected (see Appendix C). This was found to be effective for low point sample densities, but as the density increased, it was clear that the option to select a number of points and classify them simultaneously would reduce the time taken to conduct an assessment (see Appendix D). To effectively present the scale of burning, the proportions of each class are summarized in a table, and a map of the square is produced as a raster with pixel sizes equivalent to the grid spacing.

Software development

As a sample grid is created for individual images, VBA code was written to obtain the minimum X and Y extents of an image, and store these values in variables to provide a starting point for a cyclic point creation. If a number of images are being viewed in the map document, a drop down list of the layers available enables selection of the required image. The amount by which the edge sample points are inset from the edge of the image was predefined for each grid size, and by use of nested loop functions, the points for each X coordinate were created by successively adding the grid spacing on the Y coordinate. ESRI common dialogue boxes were called to facilitate navigation to locations for creating and saving files.

Classification on a point-by-point basis was developed to use a loop function to successively select the point for update, and centre the image on the selected features' envelope. An update cursor was used to write to the attribute table. The functionality to select a number of points manually used the same cursor to write multiple attributes simultaneously, and graphic markers were coded to appear above points that had been classified to avoid repeat classification.

The summary table was created using the dissolve function and added as a standalone table. To create the raster file each sample point is converted to a pixel equivalent to the grid spacing in size, and possessing the point's class field as its value.

Aerial photograph interpretation and ground survey

English Nature identified 12 environments in the PDNP on which API and ground survey could be conducted to investigate the effect of environment on consistency of interpretation. These environments consisted of three habitat types (dry heath, wet bog and dry bog), at high and low altitudes, located in both the East and West of the National Park. A height of 350m was selected as the division between high and low altitudes and OS Easting 412000 as the division between East and West. Two squares of each environment were originally intended for ground survey, but due to the project coinciding with the red grouse shooting season, only ten 1 km squares with imagery captured in 2003 and evidence of burning were accessible (Figure 2). The environments covered in the analysis are summarized in Table 3.

Table 3. The distribution of sample images in the range of environments selected to investigate the effect of environment on consistency of interpretation.

Location	Altitude	Dry heath	Wet bog	Dry bog
East	High			2
	Low		3	
West	High	1	1	
	Low	3		

A point sample grid of 100m spacing was created for the ten sample images, and the points classified on a point-by-point basis. Where sample points fell on small linear features such as vegetation boundaries or streams, the cover to the north or east of the boundary was classified (east-west or north-south running boundary respectively) as applied in the LUCAS survey (Bertin, 2003). In instances where the point fell in vegetation mosaics, the dominant species was used to identify the class. Where *Calluna* was dominant, its relevant class was assigned; else a class 0 was assigned. Land cover other than heath was always classified as class 0.

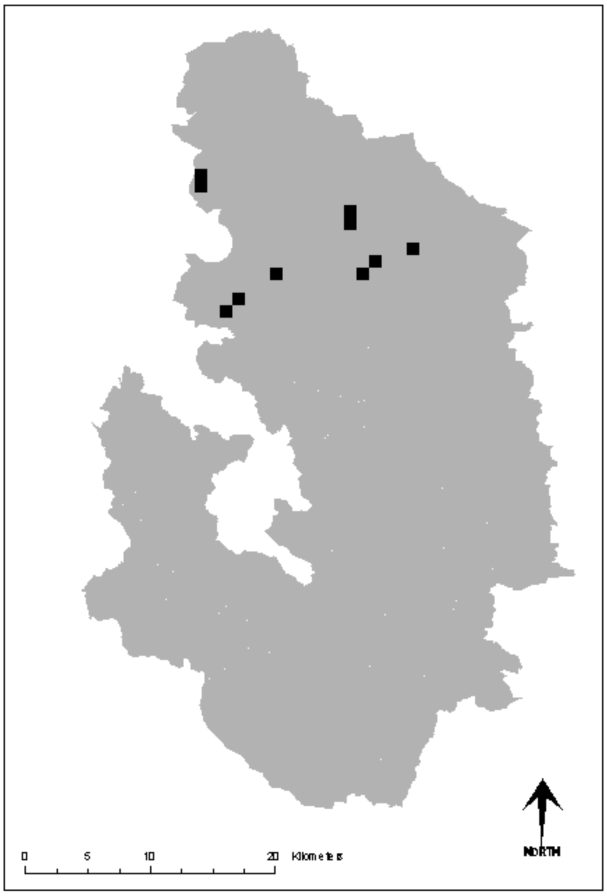

Figure 2. Location of sites in the Peak District National Park.

A 12% sub sample of points was randomly selected for ground survey, and included 25 samples of each class. WAAS enabled GPS units were used to ensure accurate identification of the point locations on the ground. Estimates of the accuracy of API were made following Story and Congalton (1986). The mean time taken to interpret the images was extrapolated to estimate a mean time required to interpret a 1 km square for each point density using the point-by-point method. Analysis of the point density sampling accuracies and interpretation time was conducted.

Digitisation compared to the point sampling protocol

As the images interpreted were specifically chosen and contained intense levels of management/burning, 20 further images were randomly selected from the extent of the National Park to give a better representation of the range and spatial distribution of burning management and allow estimation of the time it would take to interpret the whole Park. All images were interpreted by digitisation and a 35 m point sample grid, which as indicated in the results, was the grid size determined to achieve the required level of accuracy of area estimation. The functionality to classify a number of points simultaneously was employed. Analysis of interpretation times using both methods was then conducted. If digitisation were the method selected for the development of a protocol, a similar GIS customisation would have been developed to semi-automate the creation of a square binding the extent of each image and thus this time was assumed to be equal to the mean time to create a sample grid.

RESULTS

Accuracy of sampling technique in determining the area of burn scars

The mean proportionate error (MPE) of the estimations of area of class (by square) is shown in Figure 3, and is clearly a function of the grid spacing, and hence the number of points in the sample.

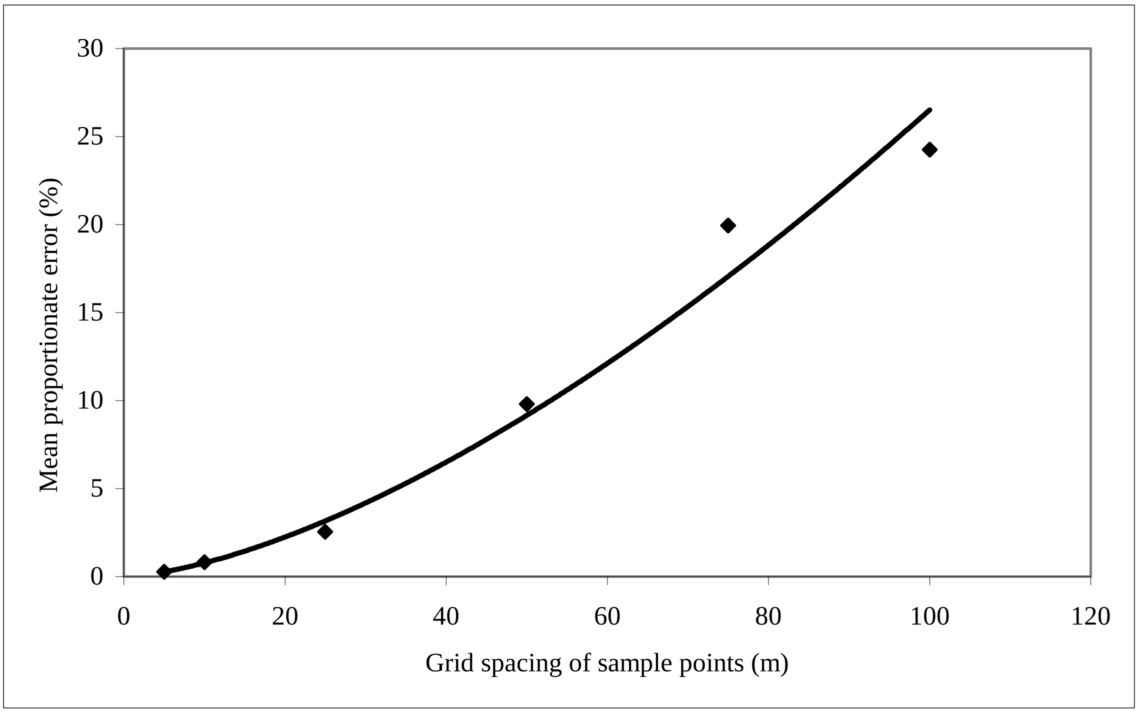

Figure 3. The effect of the sample point density on the mean proportionate error. For a grid spacing of x metres: MAE = 0.0227 * $x^{1.5341}$; R^2 = 0.99.

The grid spacing required to achieve the target accuracy of 95% (MPE of 5%) was 33.7 m and was rounded up to 35 m (841 points per km^2). At 35 m the achieved accuracy was 93.8% (MPE of 6.24%).

As the mean proportionate error does not quantify the estimation error in terms of area, this error was also calculated, and Table 4 shows that for a 35 m grid the mean error in estimating the area of a class was 0.28 ha at the level of 1 km^2. The mean area of a class per km^2 was 10.51 ha, and therefore the mean error in estimating the area of a class per km^2 is 2.66% of the true area (97.3% accurate).

Table 4. Errors in estimate of area of classes 1, 2 & 3 at level of 1 km^2.

Grid size (m)	100	75	50	35	25	10	5
Number of points	100	169	400	841	1600	10000	40000
MPE (%)	24.48	19.92	9.85	6.24	2.56	0.83	0.28
Percentage of class (1,2,3) estimates better than:							
5%	24.07	25.31	43.21	64.20	86.42	100	100
10%	38.89	48.15	69.14	87.04	97.53	100	100
20%	62.96	70.99	88.27	91.98	100	100	100
Min proportional error (%)	0.08	0.01	0.07	0.06	0.02	0	0
Max proportional error (%)	153.44	103.69	127.62	56.70	16.32	4.07	2.18
Mean area error (ha)	1.16	1.04	0.52	0.28	0.16	0.05	0.02
Mean error estimating class area (%)	11.03	9.89	4.95	2.66	1.52	0.48	0.19

Relation between class area and estimation error

Figures 4 & 5 show the effect of the size of the area of class on the proportionate error, and it is clear that smaller areas are estimated with greater proportionate error. At the level of individual polygons, the same error trend is evident (Figure 6), but the proportionate errors are much greater than at the class level. For a 35 m grid, an accuracy of 71.2% (MPE of 28.8%) was achieved, while the mean error in estimating an area of a polygon was 0.09 ha. As the mean polygon size was 0.77 ha, the mean estimation error was 11.2%.

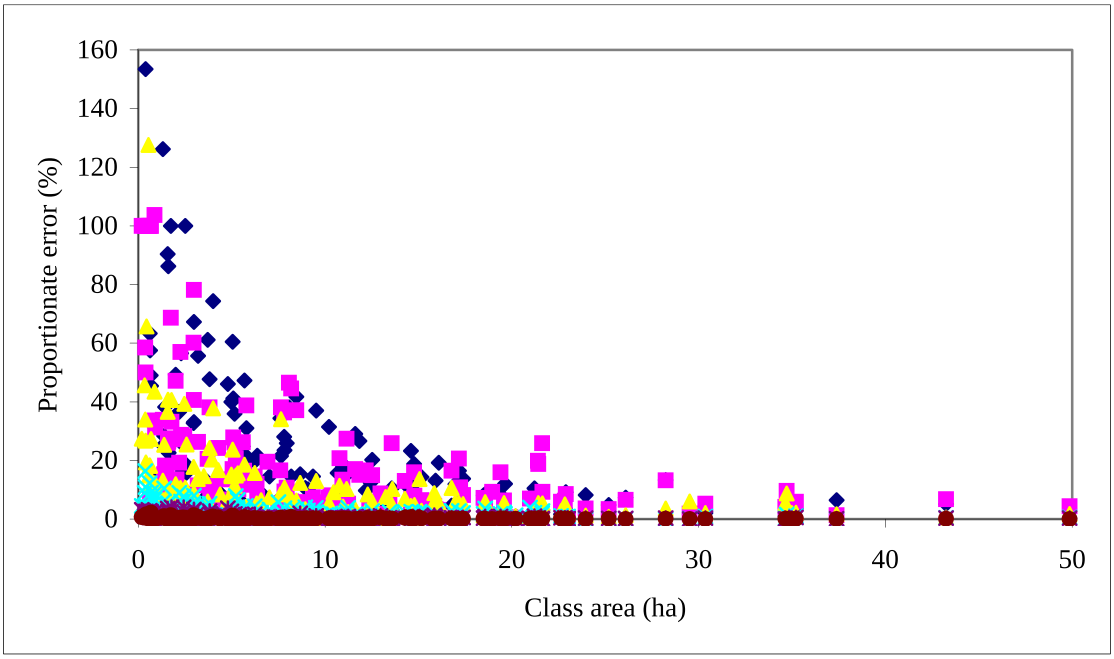

Figure 4. The effect of the class area on estimation error using sample grid spacings of:

◆ 100m ■ 75m ▲ 50m × 25m ✱ 10m ● 5m

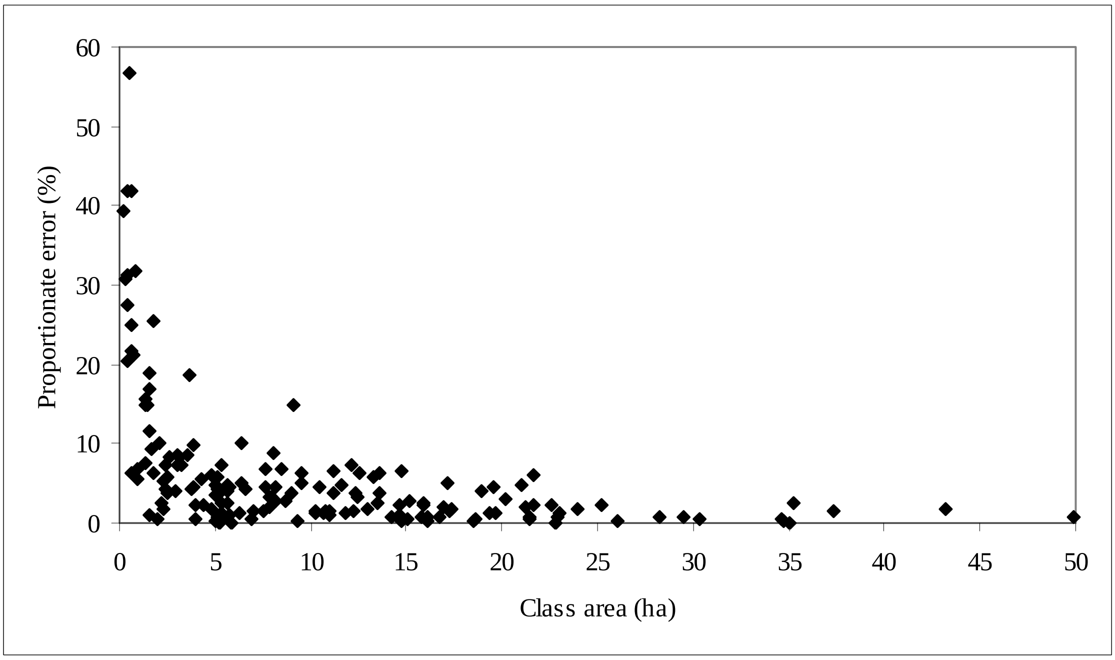

Figure 5. The effect of the class area on estimation error using a sample grid spacing of 35m.

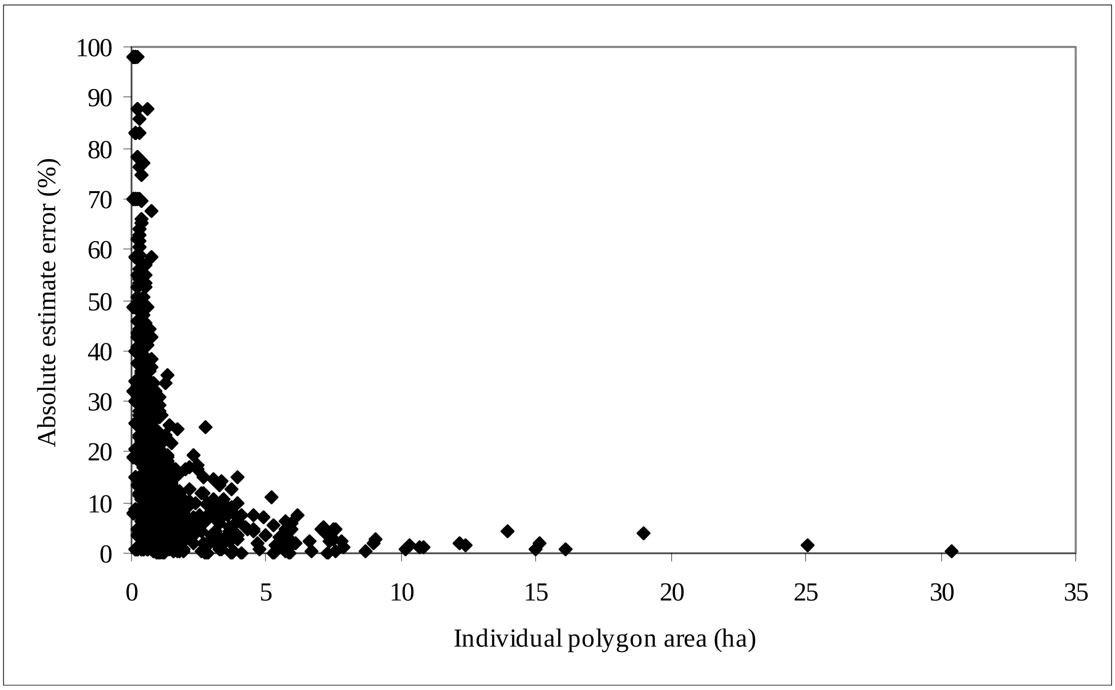

Figure 6. The effect of polygon area on estimation error using a sample grid spacing of 35 m.

Location of the grid

The four repeats of moving the position of the grid did not produce significantly different estimations compared to the grid in its original position at the 95% confidence interval (Table 5), and will therefore not be considered further.

Table 5. T-test analysis on the mean accuracy for repeat estimations with different sample grid locations.

Variable	Mean (%)	Standard deviation	Number of samples	Difference (means)	Difference (std dev)	t	df	p[1]
Original	6.24	8.92						
Repeat 1	5.34	6.27	162	0.89	7.89	1.44	161	0.15
Repeat 2	6.94	12.79	162	-0.70	9.78	-0.91	161	0.36
Repeat 3	6.43	8.40	162	-0.19	5.15	-0.47	161	0.64
Repeat 4	7.14	11.35	162	-0.90	7.03	-1.63	161	0.10

[1] at 95% confidence level marked differences are significant at $p < 0.05$.

Accuracy of API

The overall accuracy of classification at class level was 80%, which includes class 0. Removal of this class results in an overall accuracy of *Calluna* classification of 76% (Table 6). Aggregation of classes 1&2 and classes 3&4, however, showed the accuracy to be 96% with class 0 removed (Table 7).

Table 6. Correlation table summarizing the accuracy of API at class level.

		API						
		0	1	2	3	4	Total	Producer Accuracy (%)
Reference Data	0	**24**		1		1	26	92.3
	1		**18**	1			19	94.7
	2		7	**21**			28	75.0
	3			2	**18**	5	25	72.0
	4	1			7	**19**	27	70.4
	Total	25	25	25	25	25	**125**	
	User Accuracy (%)	96	72	84	72	76		

Overall accuracy (excluding class 0) = 76%.

Table 7. Correlation table summarizing the accuracy of API at aggregated class level.

		API				
		0	1 & 2	3 & 4	Total	Producer Accuracy (%)
Reference Data	0	**24**	1	1	26	92.3
	1 & 2		**47**		47	100.0
	3 & 4	1	2	**49**	52	94.2
	Total	25	50	50	**125**	
	User Accuracy (%)	96	94	98		

Overall accuracy = 96%.

Sample grid size and interpretation times

The mean time taken to interpret the photography using a 100 m point sample grid was extrapolated to estimate the mean time required to interpret a 1 km square for each sample grid size. The estimated mean time to conduct API on a point-by-point basis using a 35 m grid is 1.47 hours (Table 8).

Table 8. Estimation of time taken for API per km^2 on a point-by-point basis.

Grid size (m)	100	75	50	35	25	10	5
Number of points	100	169	400	841	1600	10000	40000
MPE (%)	24.48	19.92	9.85	6.24	2.56	0.83	0.28
Time taken for API (hrs per sq km)	0.18	0.30	0.71	1.47	2.84	17.73	70.93

Digitisation compared to the point sampling protocol

Comparison of the interpretation times using the point sample and digitising is shown in Figure 7. The mean times taken to interpret 1 km^2 is shown in Table 9, and indicates that a 35 m point sample grid is approximately four times faster than digitising.

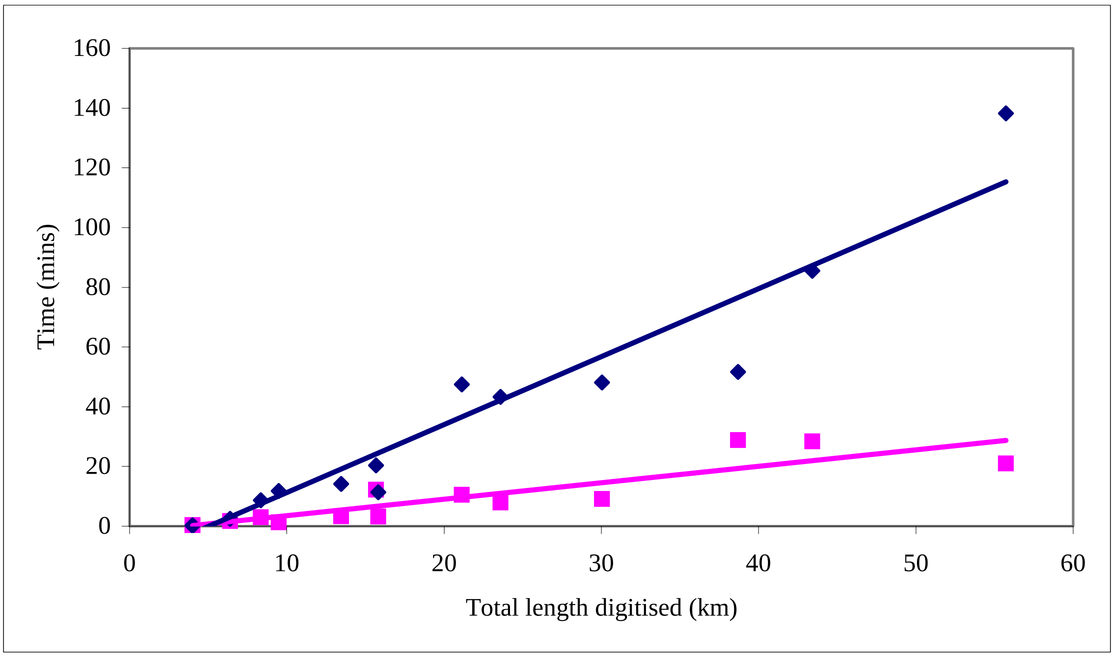

Figure 7. The effect of the total length of digitised polygon edge on interpretation time. Interpretation methods; ◆ digitisation, ■ 35 m point sample protocol.

Table 9. Mean interpretation times per 1 km^2 for point sample and digitisation.

Interpretation method	Mean interpretation time per 1 km^2 (minutes)
Digitising	24.2
35 m point sample	6.6

Mapping of visible evidence of burning

In addition to the tabulated statistics of the proportions of each class in a 1 km square, the raster map produced from the sample points provides visual representation of how the *Calluna* classes are distributed spatially (Figure 8a & 8b). It is notable that the majority of the digitised polygons are distinguishable in the raster and are very similar in dimension with 35 m pixels.

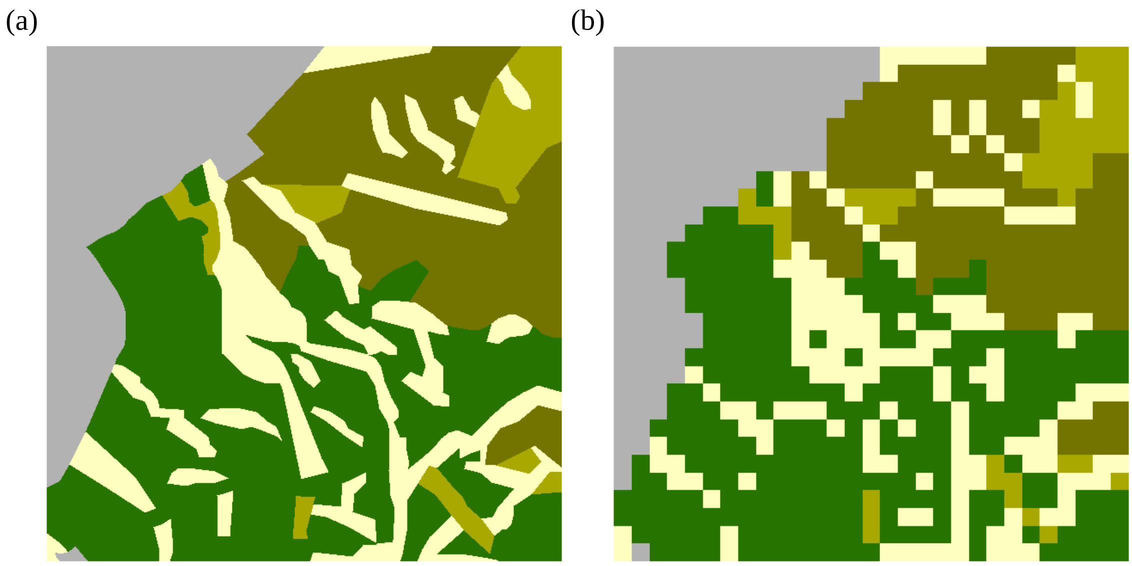

Figure 8. Visual representation of the spatial distribution of Calluna classes; (a) digitised polygons, (b) raster map produced from 35 m point sample grid.

Converting the raster map to a vector format smoothed some of the pixellated features, but did not significantly improve the visual representation.

DISCUSSION AND CONCLUSIONS

Point sampling

As expected, the results of the statistical analysis confirm that as the number of sample points increase, the accuracy of area estimation improves in a systematic way. Parties that are interested in obtaining assessments of the scale and extent of burning do not have the time or funds to conduct full digitisation projects. The analysis conducted in this research indicates that a point sample grid of 35 m is capable of producing proportional area estimations that are 94% accurate, with the actual area estimated being 97% accurate. The protocol developed in this paper enables the 35 m point sample to be applied four times faster than digitisation. Whilst the analysis also indicates that the estimations of individual burns are much less accurate, it is the landscape scale of the features that is of interest.

It is arguable that an automated object based classification using software such as eCognition might achieve a similar accuracy at a further improved rate per kilometre square. However, there is no literature on the application of the software to this specific task that could provide an indication of how much user interaction is required to train and clean the data. If a routine burn assessment were to be carried out, perhaps by different people each time, the training requirements for the point sample protocol are much less than those required for training on a software package. Improvements in the classification ability of such software may also change in time, whereas a subjective interpretation of photography is likely to produce consistent results. Agreement between individual interpreters during API was found to vary from 81% to 87% in the MLCNP project (Bird *et al*., 2000).

Aerial photograph interpretation and ground survey

A preferable agreement figure for classification is usually considered to be better than 85% (Bird *et al*., 2000), which indicates that the classification accuracy of *Calluna* classes in this investigation did not show good agreement. Yet, at the aggregated class level, a very good agreement of 96% is achieved. The remnants of compression visible in the photography is likely to have caused these errors at the class level, since these pixellated features prevent the texture of the *Calluna* canopies being viewed. If uncompressed full .tiff format images were available, discrimination between classes is likely to be much improved.

To further confound the issue, it was apparent on numerous occasions on the ground that there are no clear-cut divisions between one class and the next. The most pronounced difficulties in interpretation on the ground are at the class 1/2 and class 3/4 boundaries. The difference between a late class 1 and an early class 2 is very subjective, particularly where the *Calluna* has regenerated to a height of perhaps 10-15 cm, but the canopy is still very open. In this stage due to the canopy openness it should be classed as a class 1, but by the height of the plants it is clearly more established and could be classed as class 2. Similarly a late class 3 can be very healthy looking, but possess an uneven canopy. These two distinct boundary problems are very clear in the correlation table, as aggregation of these boundary classes improves the overall accuracy to 96% agreement. There seemed to be no significant problem distinguishing the class 2/3 boundaries. The aggregated class level may however provide sufficient information on burning practices for an assessment, with the aggregated class 1/2 representing recent burns and the class 3/4 representing old burns.

In many of the areas surveyed, the proportion of *Calluna* that had reached the class 4 stage was visibly less than was apparent in the photography, and 20% of *Calluna* interpreted as class 4 was class 3. Although better resolution imagery may have reduced the misclassification, it is evident that the frequency of the burning rotations was such that the *Calluna* rarely reached this latter phase, as found by Bardgett *et al*. (1995). It was also evident that new burns since the capture of the photography made classification of what was present before burning somewhat of a probability exercise. Hester & Sydes (1992) suggest that 90 +/- 5 % of recent burns are still visible 8 years later, but it was noted in the ground survey, viewing an image that contained a combination of 1999 and 2003 photography, that in the 5 years since the 1999 image was captured, the regeneration of the *Calluna* was such that it masked the majority of the recent burns visible in 1999. This demonstrates that for a full mapping survey, all imagery acquired must be of the same year to provide an accurate assessment of the scale of burning, particularly if ground survey is a coincident part of the assessment.

Mapping of visible evidence of burning

Although a raster map produced from a 35 m sample grid, is equivalent to a reduced resolution LCM2000 product, manual API has overcome the confusion found in automated classification. The mean accuracy of the area of each class in 1 km^2 is 97%, and this representation is suitable for a landscape scale burn assessment map.

Further GIS analysis could be conducted on the raster, perhaps to visualise the most intensely burned areas or indicate proximity to watercourses by use of distance buffers.

Peak District burn assessment

Estimation of the time taken to assess the scale of burning on the 550 km^2 of moorland in the PDNP by use of the protocol and digitising is shown in Table 10.

Table 10. Summary of estimated times to conduct burn assessment in the PDNP.

	Mean interpretation time per 1 km2 (mins)	Estimated time to assess PDNP - 550 squares (weeks)
Digitising	24.2	3
35 m point sample grid	6.6	12

Further application

The analysis of the protocol developed in this paper indicates that it is viable for producing a landscape scale assessment of the scale and extent of burning, in a quarter of the time required to fully digitise an assessment, whilst retaining an area estimation accuracy of 94%. If the protocol was applied to smaller areas, such as individual estates under management, it is feasible to apply a higher point density. A 25 m grid providing area estimation accurate to 97%, would provide a good basis for management decisions to be made.

The API was based on colour aerial photography, but use of Infrared imagery could help classification by way of an improved spectral difference between the classes, particularly due to the openness of the canopy.

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APPENDIX A

Locating digitised squares

The 97 1 km squares were contained in a single ESRI ArcGIS shapefile, indexed by a square ID (SQID). A toolbar was created and shortcut button coded to allow the user to enter the SQID of interest and select all the features within the square. The 'zoom to selected feature' was added to the toolbar and became active once a square was selected (Figure A).

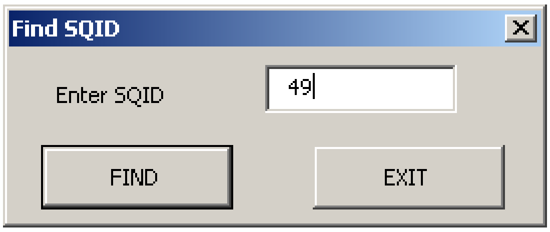


Figure A. Tool developed to locate a digitised square within the shapefile.

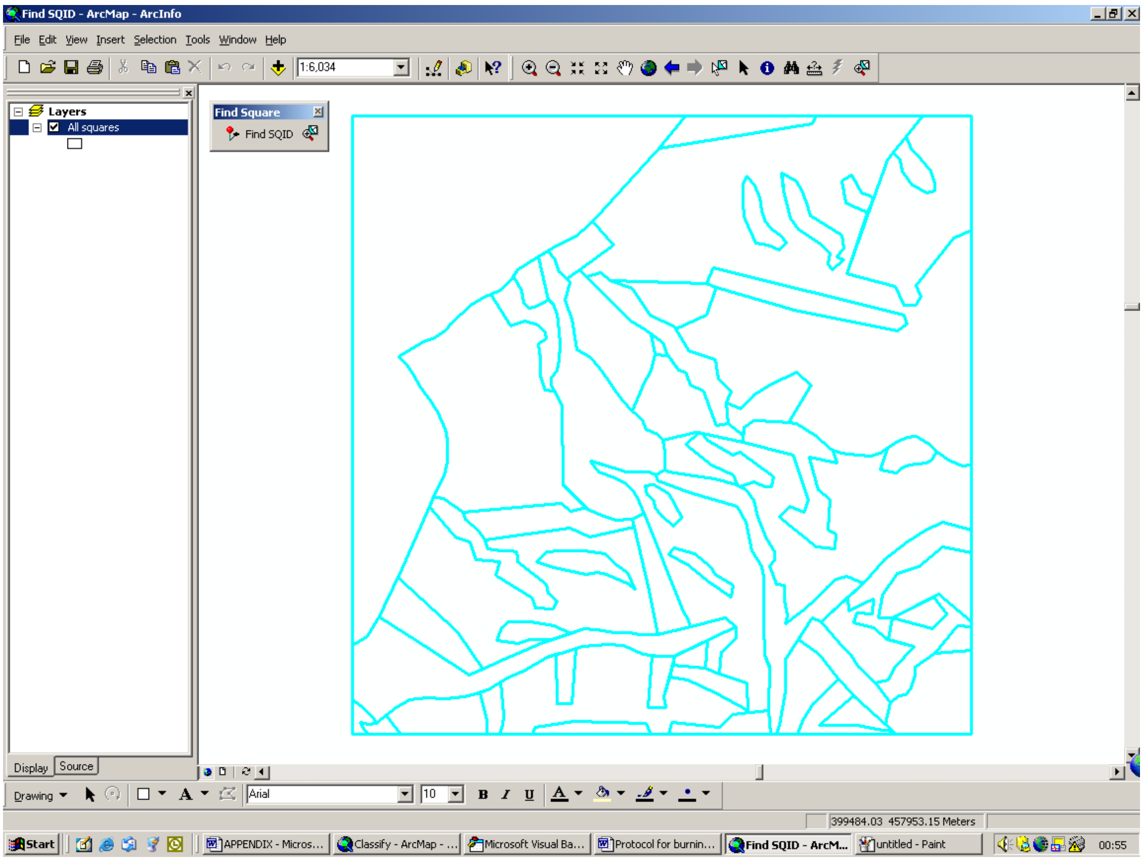


Figure B. The square of interest selected and centred on the user screen.

Semi-automated GIS tool to create predefined grid sizes

As the grid sizes to be used in the analysis were predefined, a toolbar was created and a shortcut button added for each sample grid size (Figure 1).

Figure C. Toolbar containing shortcuts to predefined grid sizes.

The user forms that the buttons called were coded with the grid spacing and inset from the edge, and the location for the shapefile to be saved to. Data required was the minimum X and Y coordinates of the square and a filename for the grid to be created. The coordinates fields were coded to populate with three zeros.

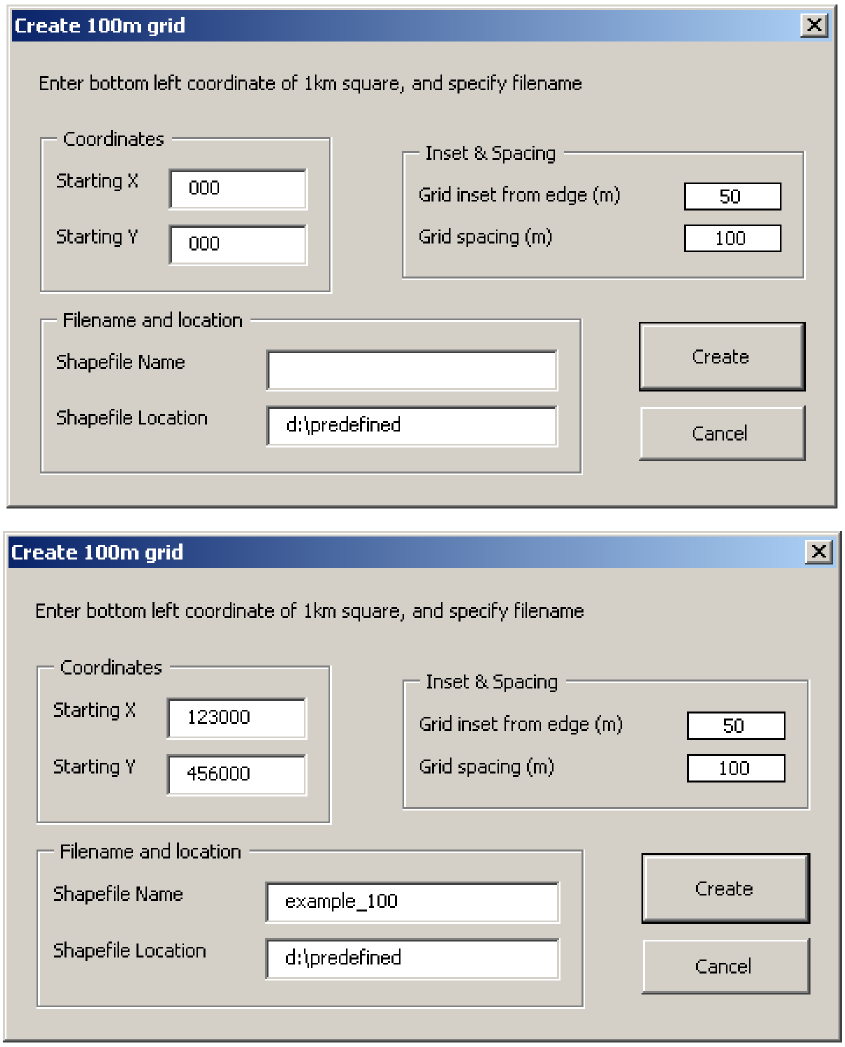


Figure D. The user forms to create the point sample grids.

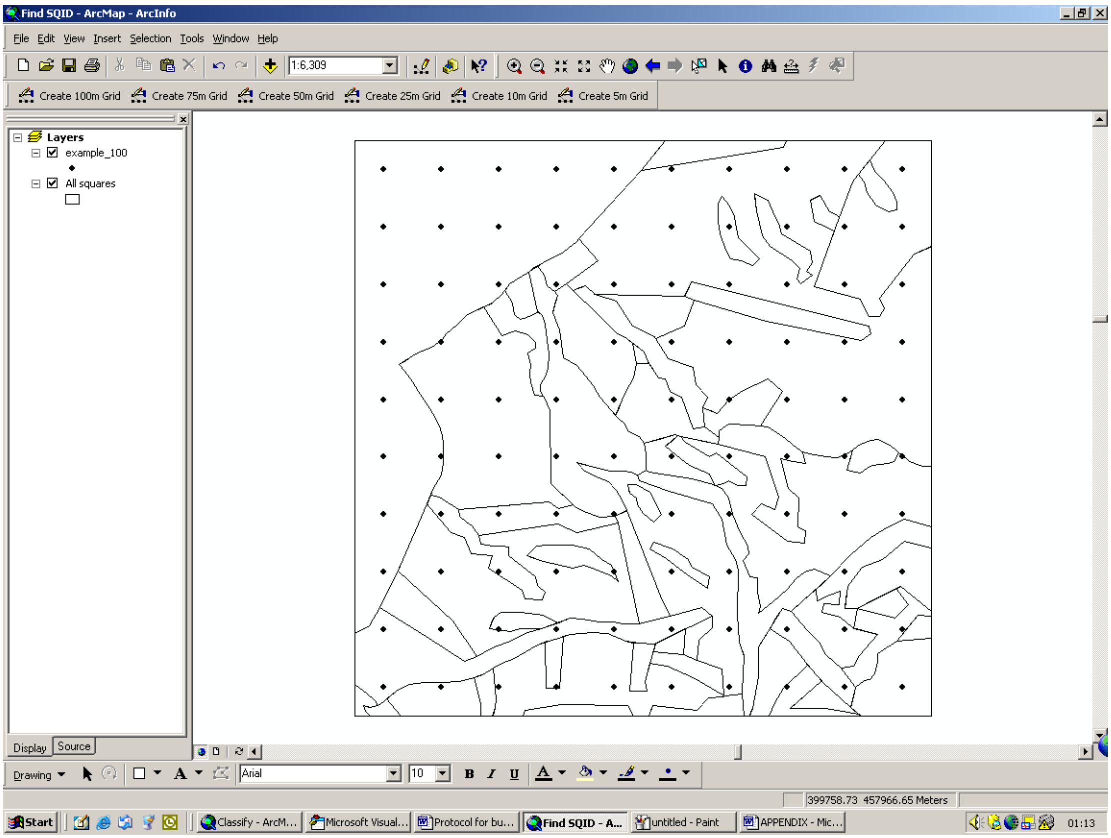


Figure E. Example of a 100 m grid generated over a 1 km digitised burn square.

Obtaining area estimates at different point densities

For 100m, 75m and 50m grid spacings, point sample grids were created for all 97 squares, copied into one shapefile and the point in polygon macro run simultaneously. As the point density increased the amount of processing required to copy large number of points caused several errors. A count tool was developed to add a count field, and populate with the number of points falling in each polygon, but this was too slow to be performed on all the squares at once.

Therefore a new method was devised for grid sizes of 25m, 10m and 5m. The grids were converted to coverages, and batch files written using the identity command to run in ArcInfo workstation. This allowed quick extraction of the data, as there were no graphics being displayed utilising vital memory.

The majority of the data processing to was conducted in Microsoft Access, as Excel was not able to process the number of rows created.

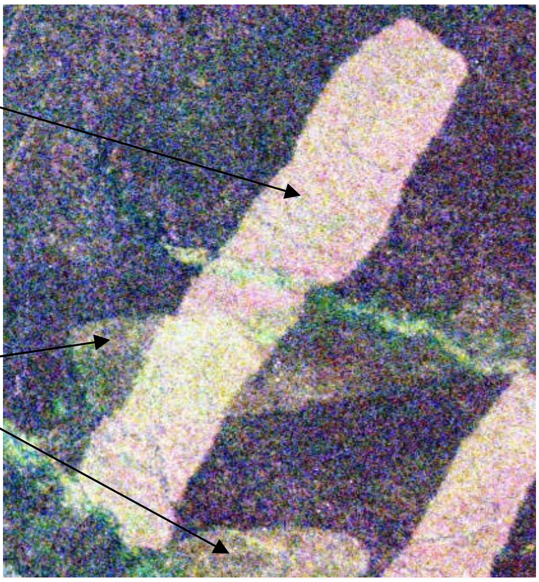
Appendix B

Calluna classification

Examples of the appearance of Calluna classes in aerial photography as suggested by Thomas *et al*. (2004) are shown in figure G.

Areas of Class 1 (diagonal) overlying area of Class 2. The smooth texture and light colouration of a burn patch with no apparent *Calluna* regeneration defines Class 1.

The apparent, but incomplete, canopy of regenerating *Calluna* shown in the near horizontal patches define Class 2.



Two strips of Class 3 lying within a matrix of Class 4. The darker and smoother textured nature of a dense canopy of regenerating *Calluna* is clearly visible.

Once the late mature and degeneration stage of *Calluna* growth is reached the texture become noticeably 'lumpy' and the area lightens as stem and ground becomes visible.

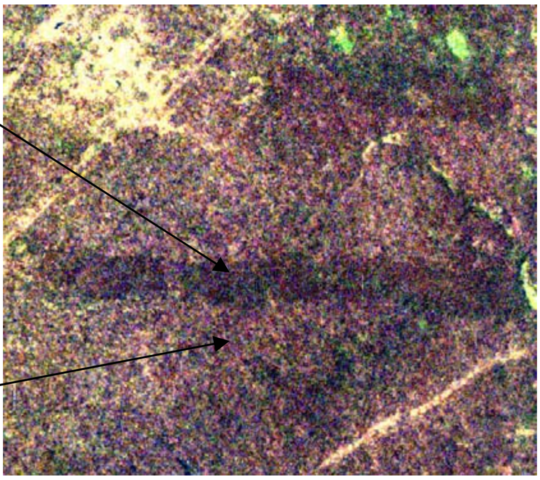


Figure G. Examples of the appearance of burn classes in 25cm aerial imagery (after Thomas *et al*., 2004).

From some of the photography used in this study, Figure H indicates examples of all 4 classes of *Calluna*.

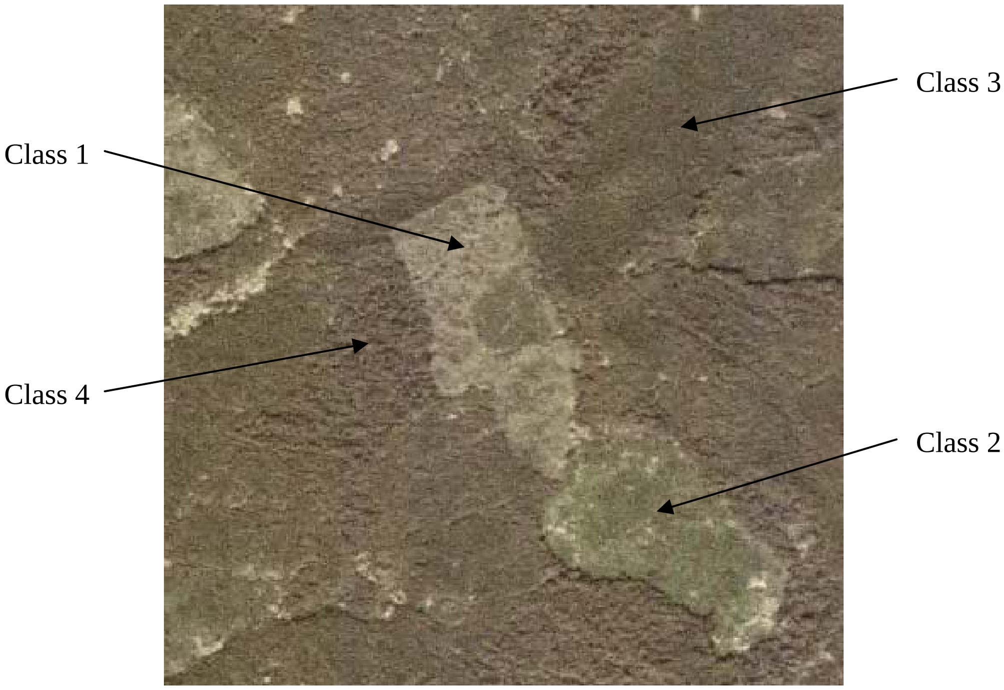


Figure H. Examples of all classes of *Calluna*.

Figure I indicates examples of patches of classes 1 to 3.

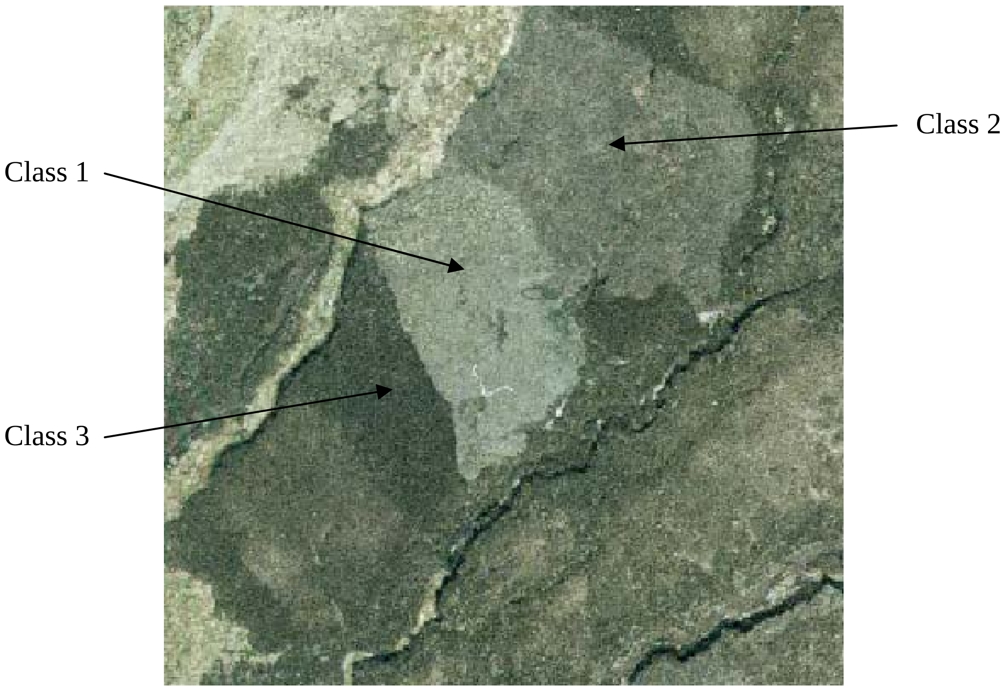


Figure I. Examples of *Calluna* classes 1 – 3.

Appendix C

GIS point-by-point classification tool

The semi-automated tool to create the point sample grids was modified for use with aerial photography. The tool automatically obtained the extent of the image, and only a filename was required. A new toolbar was created with a button to call the form to classify the points. Once the user has set the magnification, opening the form highlights and centres on the first point (Figure J).

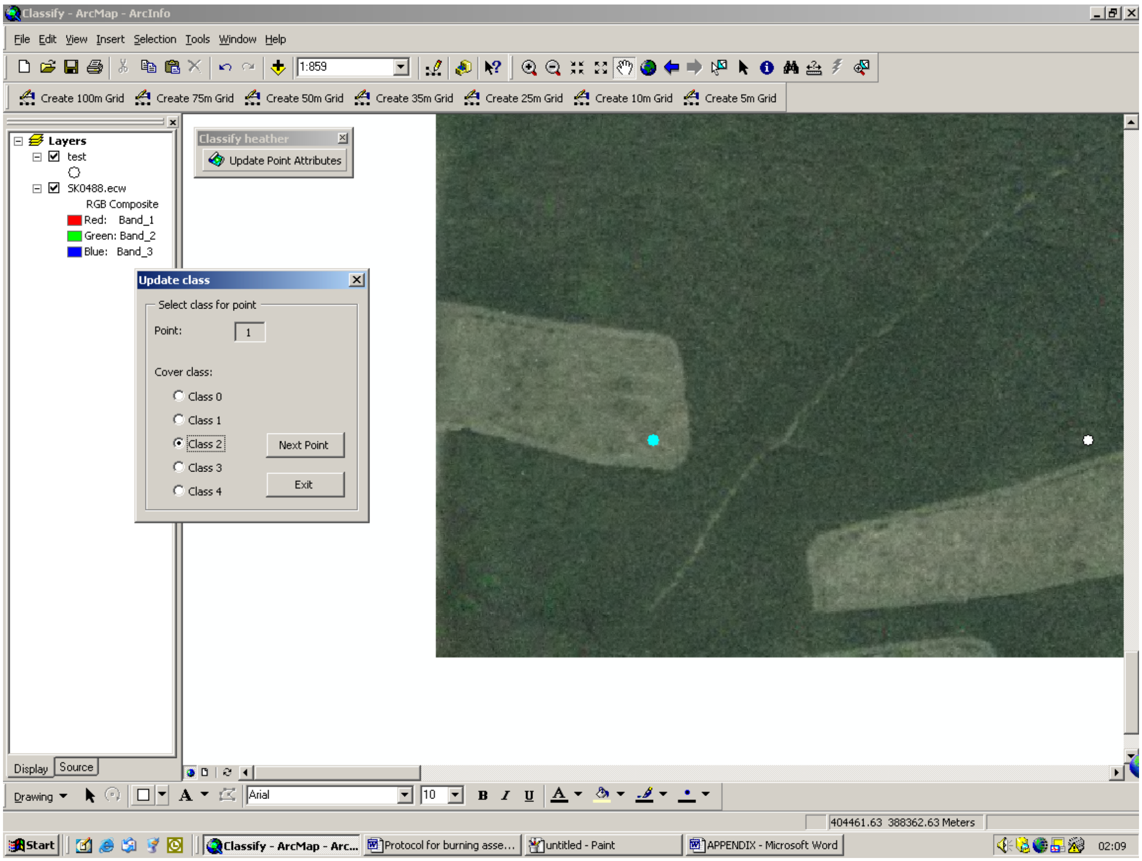


Figure J. As the form is opened, the first point for classification is highlighted and centred.

Once the selection is confirmed, the next point is highlighted and the image re-centred, and continues until all points are updated.

Appendix D

The final product

Modifications to the final product include a more professional front end for the user, and the functionality to update a number of points simultaneously. The toolbar with all options is shown in Figure K.

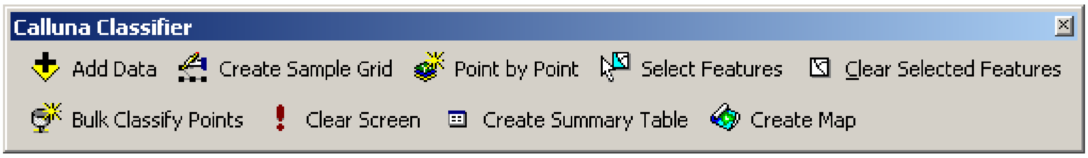


Figure K. The toolbar for the final product.

Images are loaded via the 'Add Data' button, and the user can create a sample point grid from a choice of three most relevant sizes (Figure L). In instances where more than one file has been loaded, the relevant image can be selected from a drop-down list.

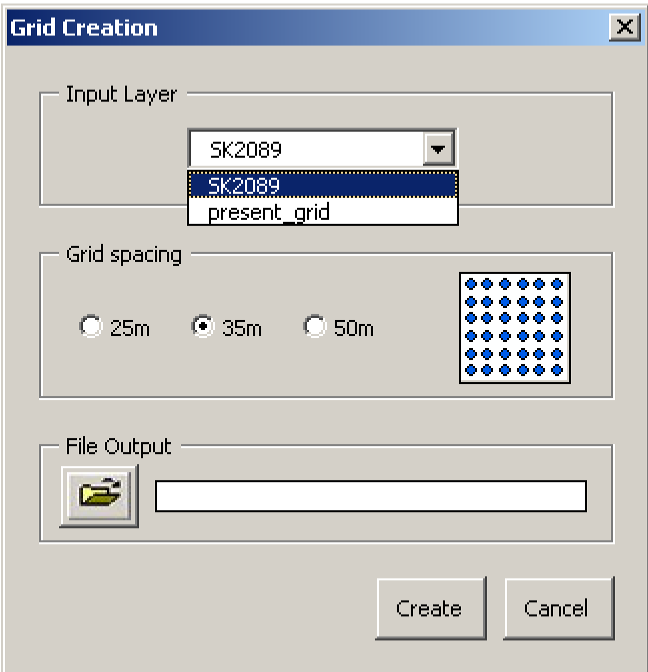


Figure L. The sample point grid creation form.

The ArcGIS save dialogue is called from the form providing the user with greater navigability to the desired storage location. Once a grid has been generated, again the user selects a suitable magnification for interpretation, and then selects the points which all belong to the same class of Calluna (Figure M).

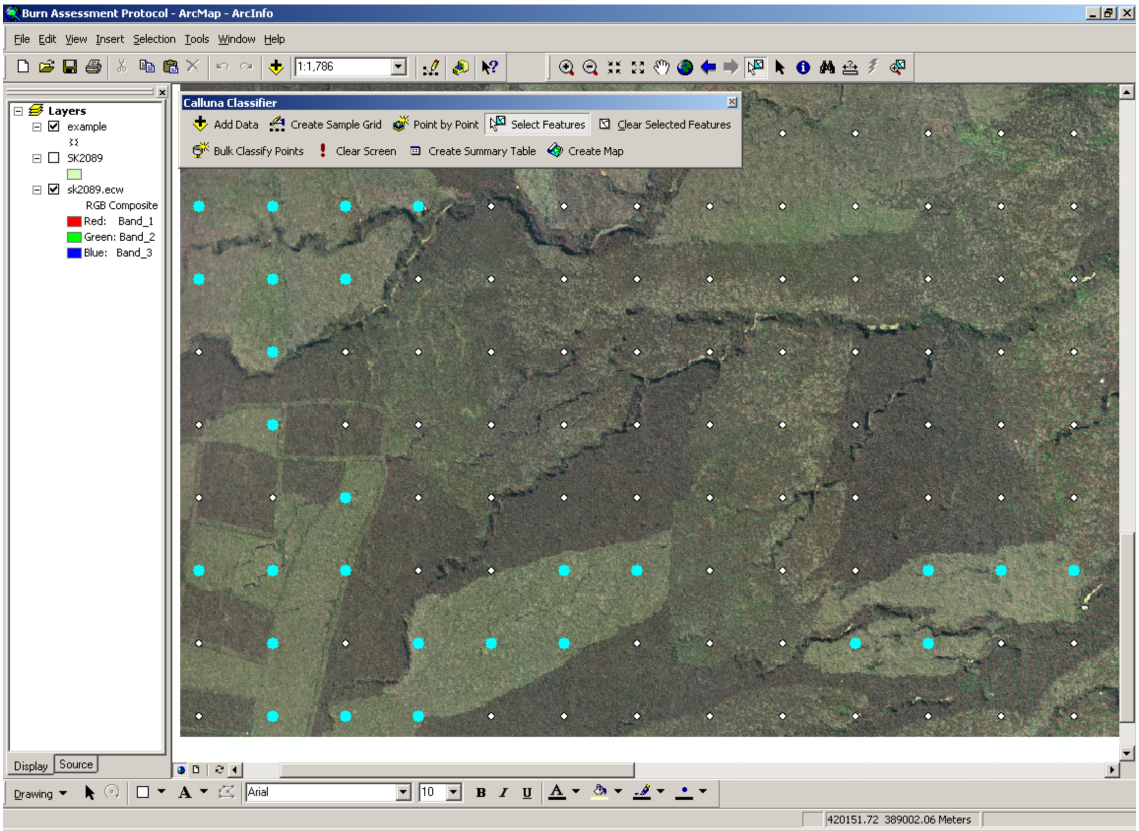


Figure M. The user selects the points to be classified.

The bulk classify points button on the toolbar opens a new form with the class options as before (Figure N). Upon update the form closes, and a graphic markers appears above all the points that have just been classified (Figure O) so that the user knows these are already done and can continue to select and classify the next set of points.

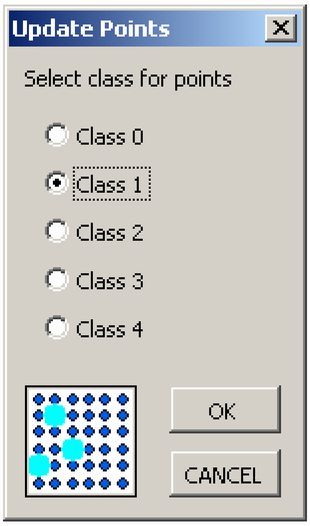


Figure N. The user selects the appropriate class of Calluna.

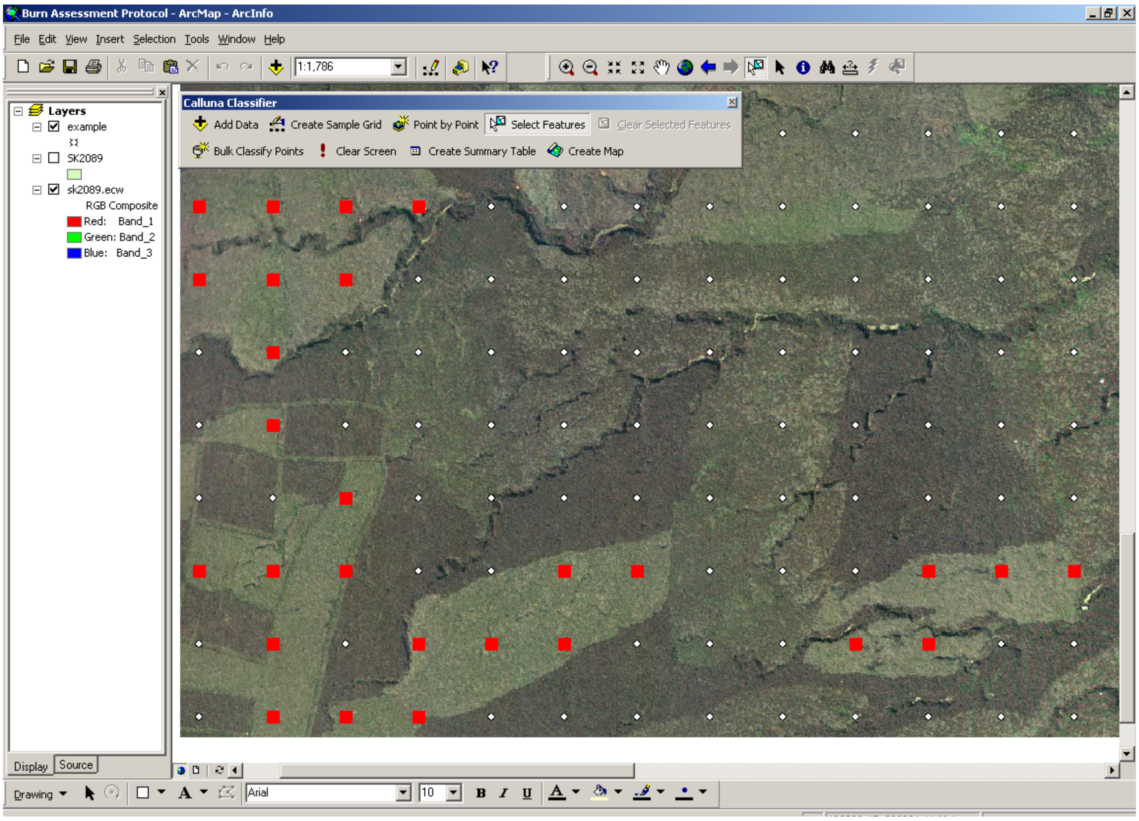
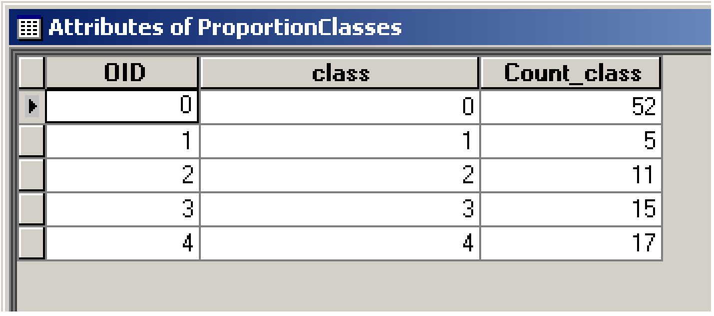


Figure O. A graphic appears above points as they are classified.

Once all the points have been classified, the user is able to produce a summary table showing the proportion of each class in the 1 km square (Figure P).



Attributes of ProportionClasses

OID	class	Count_class
0	0	52
1	1	5
2	2	11
3	3	15
4	4	17

Figure P. An example summary table showing the proportion of each class.

Further to the summary table, the user is then able to produce a raster map (Figure Q), with the pixel value based on the Calluna class. Again if a number of files are loaded the relevant point sample file can be selected.

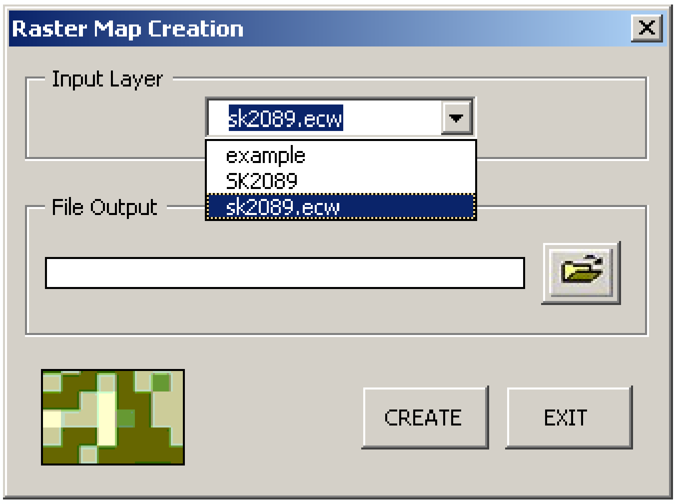


Figure Q. The form to create the raster map.

As the colours in the original image are difficult to recreate in the raster map, which has a maximum of five classes available, Figure R shows an example map created from a point sample of an image, and a digitised version of the same image to help visualisation.

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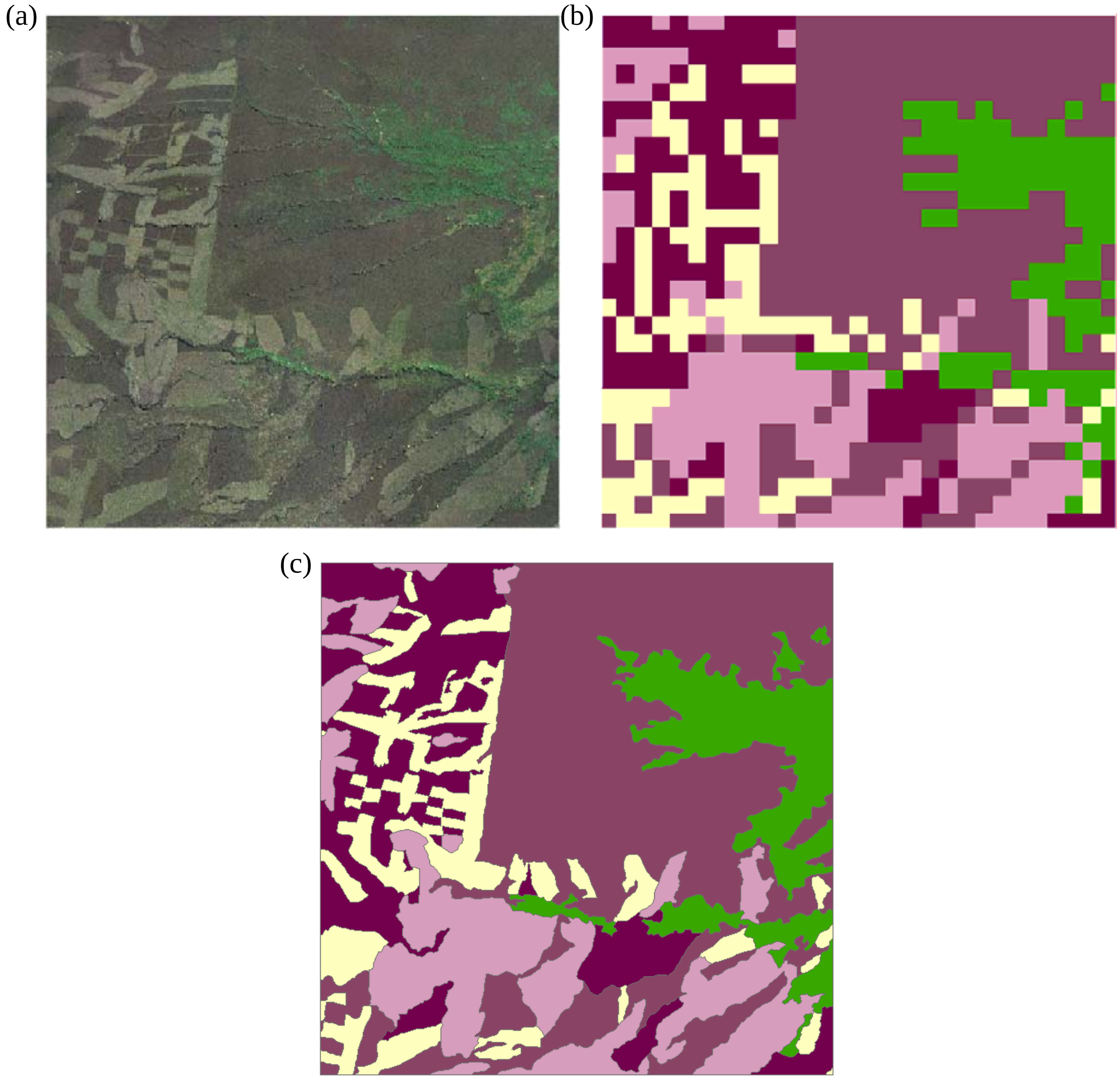

Figure R. Example raster map created from 35 m point sample grid; (a) original image, (b) raster map, (c) digitised version.