Satellite remote sensing of wildlife habitats using a multi-scale, object-based, decision-tree classifier (MOOSC)

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Abstract: This paper describes an object-based methodology devised to enable accurate and detailed habitat mapping using IKONOS VHR satellite images. The Multi-scale Object Oriented Segmentation with Decision Tree Classification (MOOSC) comprises a suite of image processing techniques applied interactively by the user in response to study area characteristics, and data dimensionality. Because of the inherent flexibility of the method, MOOSC can obtain high mapping accuracy even in the rugged terrain of the present study area combined with the low solar zenith angle of the wintertime images used. The accuracy of 90% obtained for MOOSC increases to 94% if habitat classes are based purely on physical structure rather than life form, i.e. if shrub-sized tree seedlings planted on grassy slopes are classified as shrubby grassland, which they resemble physically and spectrally, although logically they belong to the forest class. Thus the MOOSC method is able to achieve similar accuracy to stereo air photo interpretation from large scale, high quality colour photos (which achieved 95% accuracy), but at only one third of the cost.

Key words: Habitat mapping, IKONOS, MLC, Object-based classification, image segmentation

1. Introduction
Vegetation mapping as a discipline has suffered from three major problems, namely (i) the need to map at detailed level, usually over large areas, (ii) often indistinct boundaries between relevant vegetation classes, and (iii) the requirement for high levels of both positional and classification accuracy. Biodiversity conservation strategies call for comprehensive information on the distribution of species and their habitats as well as their changes over time. The slow rate of ecological change requires monitoring on a decadal time scale, and changes in habitat boundaries, or ecological succession may not be apparent unless the mapping procedures are highly accurate and subjectivity is excluded from the mapping process.

Traditionally, a combination of field survey and manual air photo interpretation has been used, to extrapolate detailed field observations over large areas. Since stereo viewing is necessary to obtain accurate identification especially in rugged terrain, this has involved high manpower requirements [1]. If the mapped boundaries must subsequently be transferred to a digital database, requiring orthorectification of individual prints, the costs of the exercise are prohibitive. Such a habitat mapping project covering the whole 1100sq.km of Hong Kong at 1:20,000 scale [2], was labour-intensive, using a combination of fieldwork and air photo interpretation, and accuracy was low except for areas visited in the field (R. Corlett, pers. comm). The habitat survey of Northumberland National Park, at 1:10,000 scale which was part of the Phase I national survey of Great Britain [3] required a total of 717 people-days. Since accuracy was shown to be poor [4], the exercise was deemed too expensive to be repeated.

Previous attempts to improve accuracy and costs using satellite images have been limited by insufficient spatial resolution of medium resolution sensors such as Landsat and SPOT. IKONOS with its 4m resolution of the multispectral sensor has greater potential, if certain problems arising from remote sensing in rugged terrain which typifies many country and national parks, can be solved. Such problems include (i) the difficulty of geometric correction caused by large vertical displacement of control points, and (ii) differences in solar illumination on opposite slopes. The low accuracy obtained by a recent habitat survey in Hong Kong using SPOT and Landsat images [5] appears to have been due to a combination of these and low resolution. For example, the accuracy of many cover types such as grassland, shrubby grassland and wetland was below 40%.
2. Objectives
This study examines the feasibility of deriving accurate habitat maps at detailed level in the extremely rugged terrain of Hong Kong’s country parks using a combination of fieldwork, air photos and satellite images. The level of detail specified is suitable for publication at 1:10,000 scale ie. such that an object as small as 10m on the ground can be resolved on the map using a line thickness of 1mm. The 4m spatial resolution of IKONOS is therefore adequate since more than 5 pixels would comprise such an object. The required class accuracy standard of 80% follows the recommendations of the USGS-NPS Vegetation Mapping Program for national scale mapping [6].

The objectives of the study are to devise an accurate and cost-effective methodology for habitat mapping in Hong Kong by
(i) a comparison between manual air photo interpretation and automated mapping from IKONOS images
(ii) a comparison between pixel-based and object-based classifiers
(iii) an assessment of the overall accuracy achievable from the automated approach
(iv) a cost benefit analysis comparing manual and automated techniques

3. The study area and images used
This comprises 7*7 kilometres of rugged terrain containing the Tai Mo Shan and Shing Mun country parks of the central New Territories, Hong Kong (Figure 1). Flat urban areas near the coast give way to steep convex slopes rising to the mountain top of Tai Mo Shan at 900m, and the Shing Mun reservoir in the south-west occupies steep-sided valleys. The average slope in the study area is ca. 23°. The climax vegetation of the south China region is evergreen broadleaf forest, which currently, due to massive clearance during WWII, is regenerating upslope from lowland valleys. Shrub, which is generally transitional to forest, and grasslands cover upper slopes and ridges, and forest above ca. 600m is classified as montane forest. Planting of non-native species such as Acacia, Eucalyptus, Lophostemon, Melaleuca and Castanopsis has taken place throughout the area but due to invasion by native lowland forest species, many plantations are not distinguishable even in the field. Only the deciduous Melaleuca quinquenervia which occurs in pure stands, is clearly identifiable.

Wintertime images are considered more useful for habitat mapping due to greater contrast between the main structural cover types, broadleaf evergreen forest, shrub and grassland.

Figure 1. Location of Tai Mo Shan and Shing Mun country parks in Hong Kong

While forest maintains high photosynthesis during the winter dry season, grassland, mainly occupying summits, dies back and exhibits much lower near infra-red (NIR) reflectance. Shrubland areas also become semi-senescent during the winter dry season due to a less established root system, with NIR reflectance mid-way between that of grassland and forest. A multispectral IKONOS image of 14th January 2001 was used for the study, having a sun elevation angle of 40° at the mid-morning image time (Figure 2a). Additionally 38 true and false colour air photos, ranging in scales from 1:6000 to 1:14000 were used for habitat mapping using stereoscopic interpretation.

4. Methods
4.1 Image pre-processing
Due to the challenging terrain of the study area, image pre-processing to produce images with high planimetric and radiometric accuracy, for input to image classification was viewed as essential to avoid the problems of previous similar projects. Image orthorectification was undertaken using the rigorous model [7], and a total of 61 carefully selected GCPs whose RMS error was limited to sub-pixel
level. Accuracy of the rectified image based on the mean accuracy of 20 check points at all elevations, was within half a pixel i.e. 2m.

The extremely low sun elevation angle in mid-January of 40 °, resulted in dark shadows over north and north-west-facing slopes, which were especially severe in the NIR band. Illumination correction was done using a version of Civco’s two stage normalization method, which was adapted [8] to correct for the extremes of steep terrain and low sun angle combined. Figure 2 (a and b) show that the correction has removed the dark shadows in the image, resulting in a near flat surface representation of the original. Atmospheric correction was not undertaken since only one IKONOS image was used for the study.

4.2 Air photo interpretation

The habitats throughout the study area were mapped using a combination of fieldwork and stereoscopic interpretation of large scale air photos (of which figures 4a and b are examples). Boundaries were first manually drawn onto the air photos and then transferred to a high resolution digital orthophoto as the mapping base, by screen digitizing. Since some aggregate classes such as shrubby grassland cannot be adequately defined with a minimum mapping of 100m², this was increased to 150m². The high quality air photo resource for the study area, on which individual tree and even shrub canopies could be identified (Figure 4), compensated for the inaccessibility of many areas in the field. At least two dates and times of photos were available thus compensating terrain shadows.

For the air photo-based study, six man months were required for fieldwork, mapping and accuracy assessment using 322 GPS points.

4.3 Maximum Likelihood Classification

Battacharya Distance measurements of the results of unsupervised classification of the multispectral IKONOS image suggested low separability between habitat types, and thus only 7 classes were input to the MLC classifier (Table 1). However, since a low accuracy (of 66%) was obtained from MLC, and previous work had noted improved results with the addition of textural measures to MLC for vegetation mapping [9,10,11] these were examined. This was done using a 4*4 grey level co-occurrence matrix (GLCM), with values representing Dissimilarity, Mean and Standard Deviation. For input to MLC, a nine-band image was created by adding the four original IKONOS bands, the NDVI and the Chlorophyll index (CI). The latter two have greater ability to separate the more vigorous evergreen forest from partially senescent grass, shrub and deciduous plantation on this dry season imagery.
Air photo and MOOSC Pixel-based classifier
Urban areas Urban
Water Water
Soil Soil
Grassland Grassland
Shrubby grassland Shrubland
Shrubland Lowland forest
Lowland forest Deciduous plantation
Montane forest

Table 1. Habitat classes at two levels of detail

However, because the addition of texture and vegetation indices to MLC resulted in only a slight improvement in accuracy (from 66% to 74%), which did not meet the project specified minimum accuracy standard of 80%, it was recognized that a method for reducing the high spectral variation within classes was required.

4.4 Multi-scale Object-Oriented Segmentation with Decision-tree Classification (MOOSC)
Multi-scale Object-Oriented Segmentation with Decision-tree Classification (MOOSC) devised during this study, partitions the image pixels into segments and uses a decision-tree approach to allocate segments to classes. The image segmentation which has been applied successfully to stand level forest inventories [9,12,13] was implemented using a region-based approach with five input parameters in eCognition. These parameters, color, shape, compactness, smoothness and scale were applied to segment the image at five levels of agglomeration. A trial and error approach was used to investigate the appropriate settings for the parameters. The mapped results of each of fifty trials were compared visually with the habitats mapped from the air photos. In order to increase the band dimensionality, a 10 band image including the original four IKONOS multispectral bands, NDVI and chlorophyll index, a DEM raster band and three texture bands was input to the segmentation algorithm.

Following this, a decision tree classification (Figure 3) was applied to the segments, based on their spectral characteristics at each level, plus the DEM. Input of the segments to the classification was done semi-automatically by the user, based on examination of the previously generated statistics from unsupervised and supervised classification, and the DEM. For example, at level 1 of the decision tree, a threshold in the NIR band was identified to separate land and water. At level 2 the CI was found to be suitable for threshold placement between woody and herbaceous classes. After level 4, only shrubland remained un-allocated in the decision tree (Figure 3).

![Figure 3. Decision-tree classifier of MOOSC methodology](image)

The CI was found to be suitable for the threshold placements between the grass, shrub and forest classes, since pure grassland and pure forest are at the extreme ends of the shrubland spectrum in this band. Therefore it was decided to add a fifth level to determine thresholds for a transitional class, shrubby grassland. Thus the spectral threshold between shrubby grassland and shrubland was computed from weighted endmember mean values for 50% grass and 50% forest, corresponding to a CI value of 1367 (Figure 4). The minimum polygon size resulting from segmentation was approximately 150m².

Accuracy assessment of the MOOSC mapping was undertaken using the 322 GPS points used for accuracy testing of the air photo interpreted habitat map. Since the GPS points were restricted to accessible locations, and since the air photo mapping proved to be highly accurate,
215 extra check points from direct air photo interpretation, evenly distributed over the habitat map were used.

Figure 4a. Colour air photo at 1:8,000 scale showing the high quality of air photos used. The outlined area corresponds to Figure 4b.

Figure 4b. Enlargement of 4a: showing ecotone (grassland (G), shrubby grassland (SG), shrub (S), forest (LF))

5. Results

The air photo mapping achieved very high accuracy of 95% (Table 2), easily within the specified minimum accuracy level of 80%. This is not surprising, due to the high quality of the air photo cover, expertise, and 180 days taken.

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
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<tr>
<td>API</td>
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<tr>
<td>MLC</td>
<td>66%</td>
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<tr>
<td>MLC with texture</td>
<td>74%</td>
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<tr>
<td>MOOSC</td>
<td>90% (94%)*</td>
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</table>

* if based on physical structure

Table 2. Accuracy of different mapping techniques

Of the automated methods, the MLC classified image obtained a low accuracy of 66% due partly to high within class ‘salt and pepper’ variability typical of VHR sensors. Additionally, many areas of lowland forest were
incorrectly allocated to the class Deciduous Plantation, due to the inability of the illumination correction to address areas of absolute shadow in the DEM. Much of this intra-class variability was eliminated by the addition of texture to MLC using a 4 * 4 window size. However spectral confusion between many classes remained, and although the addition of texture increased the overall accuracy by 8%, to 74%, this was still well below the project’s specified minimum accuracy of 80%.

By the application of five decision criteria, namely texture (GLCM), NDVI, Red band, size and DEM (elevation) at different levels of the decision tree, the MOOSC mapping achieved a high overall accuracy of 90% (Table 2). For example, it was able to remove all of the confusion between lowland forest and deciduous plantation using size, since the misclassified forest segments are much smaller than the plantations. The very high accuracy achieved by MOOSC is particularly remarkable since 4% of the inherent error due to new plantations on grassy hillslopes, which also accounted for half the error in the air photo mapping. If these young plantations were to be classified based on physical structure (since physically they are shrubs within grassland) and re-allocated to shrubby grassland or shrubland, the accuracy of MOOSC increases to 94%. Approximately 4% of the remaining error occurs at the boundaries between the three transitional classes: grassland, shrub and shrubby grassland (Table 3). However the lowest accuracies achieved are still above the specified minimum of 80%.

Figure 4b illustrates the operation of segment unmixing to determine the spectral threshold between grassland and shrubby grassland. It compares the nature of the grassland to forest ecotone on an air photo with the IKONOS CI values along a traverse. Pixel values (thin line) across the ecotone are noisy, and placement of the boundary between grassland and shrubby grassland is arbitrary. Segment values however, (thick line) are discrete, and the shrubby grassland segment with CI values of 1446 would, in this case, have been correctly allocated using the segment unmixing method, since the weighted endmember threshold is 1367.

Overall, a total of 150 man days were required for the air photo method, compared with 44 days for the MOOSC method. If manpower and image costs are considered, the MOOSC method is almost 3 times cheaper than the manual air photo method, but has similar accuracy.

6. Conclusion
Mehner et al (2001) consider that IKONOS will provide a useful additional tool for mapping upland vegetation in UK at the same mapping scale as this project, 1:10,000. Experience of the present project suggests that with a specifically designed suite of image processing algorithms combined with sound knowledge of the study area, IKONOS multispectral images may be used to replace traditional air photo techniques, at a level of accuracy far exceeding national vegetation mapping standards, even in rugged terrain which is challenging to even manual, air photo-based techniques. In view of the substantial cost advantages, and small accuracy differences observed, IKONOS appears to be the best choice for mapping at 1:10,000 scale. The vegetation mapping discipline has traditionally recognized the need for a sound knowledge of the study area. Except in very simple landscapes this is no less true of automated methods, with the additional requirement to fully understand and utilize the spectral characteristics and dimensionality of the imagery available. Thus a suite of image processing techniques, based on the MOOSC method, applied with some rule-based trial and error may give the best results for any particular study area.

Acknowledgement
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References:


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<th>MOOSC/GPS</th>
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<th>Urban</th>
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Table 3. MOOSC accuracy assessment. Figures in brackets indicate accuracy achieved if classification is based on physical structure, ie young shrub-sized plantations on grassy slopes accepted as shrub or shrubby grassland rather than forest.