Habitat Mapping in Rugged Terrain Using Multispectral Ikonos Images

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Abstract
Due to the significant time and cost requirements of traditional mapping techniques, accurate and detailed habitat maps for large areas are uncommon. This study investigates the application of Ikonos Very High Resolution (VHR) images to habitat mapping in the rugged terrain of Hong Kong's country parks. A required mapping scale of 1:10 000, a minimum map object size of 150 m² on the ground, and a minimum accuracy level of 80 percent were set as the mapping standards. Very high quality aerial photographs and digital topographic maps provided accurate reference data for the image processing and habitat classification. A comparison between manual stereoscopic aerial photographic interpretation and image classification using pixel-based and object-based classifiers was carried out. The Multi-level Object Oriented Segmentation with Decision Tree Classification (MOOSC) was devised during this study using a suite of image processing techniques to integrate spectral, textural, and spatial criteria with ancillary data. Manual mapping from air photos combined with fieldwork obtained the best result, with 95 percent overall accuracy, but both this and the MOOSC method, with 94 percent, easily met the 80 percent specified accuracy standard. The MOOSC method was able to achieve similar accuracy aerial photographs, but at only one third of the cost.

Introduction
Biodiversity conservation strategies call for comprehensive information on the distribution of species and their habitats as well as their changes over time. However, wildlife habitat mapping, as a discipline has suffered from several major challenges including:

1. the need to map at detailed level, usually over large areas,
2. often indistinct boundaries between relevant vegetation classes, requiring a large element of subjectivity (Green and Hartley, 2000; Alexander and Millington, 2000),
3. the requirement for high levels of accuracy due to the slow rate of change,
4. many wildlife reserves occupy mountainous terrain, and
5. lack of readily applicable automated methodologies because, even within the same climatic zone, vegetation communities may be highly variable, thus mapping methodologies cannot be extrapolated outside a particular study area.

Traditionally, manual air photo interpretation has been used to extrapolate field observations over large areas. Since stereo viewing is often necessary to identify habitat structure, especially on steep slopes, it is time-consuming (Green et al., 1993). Even with digital photography, large area coverage would require orthorectification of individual images, resulting in potentially prohibitive costs.

The first ever habitat survey covering the whole 1,100 km² of Hong Kong at 1:20 000 scale was undertaken by the Worldwide Fund for Nature in 1993 (Ashworth et al., 1993), using a combination of fieldwork and air photo interpretation. The resulting accuracy was low (R. Corlett, personal communication), and the maps were little used. Another such project, the 1:10 000 scale habitat survey of Northumberland National Park, which was part of the Phase I national survey of Great Britain (Walton, 1993), was carried out by air photo interpretation and required a total of 717 people-days. The exercise was deemed too expensive to be repeated (Mehner et al., 2004) given the low accuracy (Brookes et al., 2000).

Attempts to improve accuracy and costs using satellite images have been limited by insufficient spatial resolution of medium resolution sensors such as those on Landsat and SPOT through SPOT4. The low overall accuracy (approximately 50 percent) obtained by a recent habitat survey covering the whole of Hong Kong using SPOT4 and Landsat images (Environmental Protection Department, 2003) appears to have been due to inadequate resolution, combined with differences in solar illumination on opposite slopes. For example, the accuracy of many cover types such as grassland, shrubby grassland and wetland, when referenced against field GPS data, was below 40 percent (Environmental Protection Department, 2003). Generally up to the present time, high accuracy in habitat mapping is difficult to achieve (Brookes et al., 2000).

If the problem of differential illumination in mountainous terrain can be solved, the new generation of VHR satellite sensors such as Ikonos with its 4 m multispectral resolution has greater potential (Slater and Brown, 2000). However, it is recognised that image processing techniques specific to these sensors are required. Mather (1999) recommends the addition of texture to pixel-based classifiers due to the detection of micro-scale texture properties at high-resolution (see for example, Keramitsoglou et al. (2005)). Furthermore, since on VHR sensors, natural habitats are composed of many different reflectance surfaces, pixel-based classifiers are inappropriate. Thus, recent habitat mapping projects have used object-based classifiers with VHR airborne, (Ehlers et al., 2003) and satellite sensors (Bock et al., 2005; Kobler et al., 2006). These have the ability to group pixels into discrete
objects, or segments, based on both spectral details and spatial criteria such as size, shape, and local texture, and segments may be defined at different scales (Baatz and Schäpe, 2000). The method of image segmentation has also been applied successfully to stand level forest inventories (Pekkarinen, 2002; Wulder et al., 2004).

Subsequently, segments may be allocated to classes using an automated approach. For example, Kobler et al. (2006) devised a machine learning algorithm with a decision tree structure to allocate segments to habitat classes; and Bock et al. (2005) used a nearest neighbor algorithm to allocate segments derived from QuickBird images to habitat classes. Only low to moderate accuracy was achieved from these fully automated methods however, with Kappa classification accuracy of 0.6 by Kobler et al. (2006) and 0.75 by Bock et al. (2005). A study by Ehlers et al. (2003) combining spatial and spectral image parameters with a semi-automated, rule-based hierarchical procedure was able to achieve much higher accuracy, of well over 90 percent for some classes. However, the latter study was based on detailed airborne data with 0.15 m ground resolution over flat terrain, and there is no indication that similar accuracy could be achieved using satellite images over large areas of rugged terrain as in the present study.

This study evaluates a semi-automated approach to habitat mapping using Ikonos multispectral images in mountainous terrain by comparing the results with manual methods using high-resolution, stereo air photos and fieldwork. The specified mapping scale of 1:10 000 and a minimum object size of 100 m$^2$ on the ground are initially set as attainable with the 4 m spatial resolution of Ikonos. Thus, five Ikonos pixels would comprise such an object. A minimum class accuracy standard of 80 percent was also specified, following the recommendations of the USGS-NPS Vegetation Mapping Program for national scale mapping (USGS, 2006).

Three secondary objectives of the study include:

1. a comparison between pixel-based and object-based classifiers,
2. an assessment of the overall accuracy achievable from the image processing approach, and
3. a cost benefit analysis comparing manual and digital techniques.

The Study Area and Images Used

The study area comprises an 11 km$^2$ area of mountainous terrain containing the Tai Mo Shan and Shing Mun country parks of the central New Territories, Hong Kong, at 22°2'N, 114°1'E (Figure 1). Flat urban areas near the coast give way to steep convex slopes rising to the mountain top of Tai Mo Shan at 900 m only 3 km from the coast and the Shing Mun reservoir in the south-east occupies steep-sided valleys with slopes commonly 40° to 50°.

The climax vegetation of the south China region is evergreen broadleaf forest. Due to massive clearance during WWII, Hong Kong’s forests are regenerating upslope from lowland valleys (Dudgeon and Corlett, 2005). Shrub, which is generally transitional to forest, and grasslands cover upper slopes and ridges (Dudgeon and Corlett, 2005), and both are found at lower elevations following fire. In the study area, both vertebrate and invertebrate fauna show distinct preferences for either forest, grassland, or shrub habitats, while the invasion of shrubs into grassland is accompanied by a dramatic increase in fauna due to the patches of cover offered by perennial shrubs within seasonal grassland. Thus, as habitat succession proceeds to increased shrub and tree cover, the vertebrate community becomes more diverse and includes more sensitive species such as thrushes, coucals, robins, and leaf warblers (Dudgeon and Corlett, 2005). Many animals also show a distinct preference for altitude, either high or low, and forest above 600 m is classified as montane forest (Dudgeon and Corlett, 2005). Planting of non-native evergreen genera such as Acacia, Eucalyptus, Lophostemon, and Castanopsis has taken place throughout the area, but due to invasion by native lowland forest species, many plantations are not distinguishable. Only the deciduous paper bark tree Melaleuca quinquenervia, which occurs in pure stands, is clearly identifiable (D in Figure 2).
Wintertime images are considered more useful due to greater contrast between the main structural cover types, broadleaf evergreen forest and plantations, deciduous plantations, shrub, and grassland. While forest maintains high photosynthesis during the winter dry season, grassland, mainly occupying summits (G in Figure 2) dies back and exhibits lower Near Infra-Red (NIR) and green, and higher red reflectance. Shrublands also become semi-senescent during the winter dry season due to a less established root system, with reflectance values mid-way between that of grassland and forest.

A multispectral Ikonos image from 28 January 2003 having a sun elevation angle of 40° at the mid-morning image collection time was used for the study. In order to provide a frame of reference, the habitats were also manually interpreted using 38 true and false color stereo photographs, ranging in scales from 1:6 000 to 1:18 000 (e.g., Plate 1c). The boundaries were delineated onto a color digital orthophoto of 0.20 m resolution. This high quality aerial photographic resource, where individual tree and even shrub canopies could be identified (Plate 1d), compensated for the inaccessibility of many areas in the field. At least two dates and times of photos were available thus compensating for terrain shadows on some images.

Methods

Image Preprocessing
Due to the relief of the study area, geometric and topographic illumination corrections were undertaken prior to habitat classification. Orthorectification of Ikonos imagery was undertaken using Toutin and Cheng’s (2000) rigorous model with 61 GCPs from 1:1 000 scale digital maps from the Hong Kong Lands Department with known accuracy within 1 meter. Accuracy of the rectified image based on the mean accuracy of 20 checkpoints at all elevations proved to be within half a pixel, i.e., 2 m.

The extremely low sun elevation angle in mid-January of 40° resulted in dark shadows over north and north-west-facing slopes (Plate 1a), which were especially severe in the valley bottoms. This band is particularly important for vegetation discrimination, especially since the remaining three Ikonos bands are highly correlated. Illumination correction was done using the Empirical Slope Matching technique (Nichol et al., 2006) which was devised to correct for the extremes of steep terrain and low (40°) sun angle combined. The DEM was created from contours, spot correct for the extremes of steep terrain and low (40°) sun angle within half a pixel, i.e., 2 m.

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Selection of the Mapping Classes
The approach to class selection was study area specific, since classification schemes for sub-tropical regions are not well developed. Habitats were classified on a structural rather than floristic basis for three reasons; (a) since Hong Kong is on the edge of the tropics, plant communities are heterogeneous and are thus more easily recognized and delineated according to physiognomic life form, as well as their growth habit (evergreen or deciduous) (Raunkiaer, 1937), (b) evolving paradigms for the use of satellite images for vegetation mapping are based on vegetation structure (Lewis, 1994; Millington and Alexander, 2000), and (c) observed plant-animal interactions generally (Wiens, 1989; Imhoff et al., 1997), as well as in the study area (see Study Area section above). Based on the structural approach, young forest plantations on grassy slopes, which would be classified floristically as forest, were classified according to physical structure (since ecologically they function as shrubs within grassland) and allocated to shrubby grassland or shrubland. Furthermore, deciduous plantation comprising the species Melaleuca quinquenervia was also assigned a separate class, since growth habit is a plant structural characteristic, and because it is easily separable from the evergreen forest species on this dry season imagery (Figure 2). However, evergreen plantations, many of which have merged with the evergreen lowland forest were mapped as forest, since they are similar in terms of both structure and function. Nine classes, based on the plant-animal dependencies described (see Study Area section) were selected (Table 1).

Air Photo Interpretation and Fieldwork
The habitats throughout the study area were mapped using stereoscopic interpretation of large-scale air photos (Plate 1c), supported by fieldwork. Boundaries were first drawn on hardcopy prints and then transferred to the digital orthophoto as the mapping base by on-screen digitizing. The size of mapping unit, 100 to 150 m² on the ground was larger than the initially specified minimum of 40 m² because known accuracy of less than 5 m. A grid size of 2 m was chosen for interpolating the DEM to resemble the 4 m resolution of the multispectral Ikonos images, and the Sibson with slope method of interpolation was used (Dakowicz and Gold, 2003; Nichol and Law, 2008). Plate 1a and 1b show that the correction has removed most of the dark shadows in the image and produced a near flat surface representation of the original (Plate 1b and Figure 2). Although these procedures do impact the DN values, they led to a 7 percent increase in classification accuracy in a previous study (Nichol et al., 2006). Atmospheric correction was not undertaken since only one date of Ikonos imagery was used.

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Plate 1. (a) Ikonos false color, 5 km² extract of study area before illumination correction with linear contrast stretch. From bottom right to top left, a distance of approximately 3 km, elevation rises from 170 m to 800 m. Many forested north-facing slopes (S) are in shadow; (b) Ikonos image extract following illumination correction with linear contrast stretch. Shadows on north-facing slopes have been removed except for small areas in absolute shadow (S), and decious plantations of Melaleuca quinquervia (D) are the only remaining extensive dark areas in the image; (c) Color air photo of August 2002 at 1:8 000 scale, showing the high quality of air photos used. The area covered is outlined on the Ikonos image (Plate 1b); and (d) Enlarged extract of Plate 1b, showing the grassland to forest ecotone with a traverse across the habitat types, grassland (G), shrubby grassland (SG), shrubland (S) and lowland forest (LF). Traverse values represent the Chlorophyll Index values derived from the Ikonos image; thin line represents pixel values and thick line represents segment values.
investigating the “optimum scale lengths” (Marceau et al., 1994) of each mapping class, which corresponds to low spectral variability within the class. This provides a guideline as to the best resolution for identifying that class spectrally (Marceau et al., 1994), or by inference, texturally. This was using Moran’s I measure of spatial autocorrelation applied to the Ikonos 1 m resolution panchromatic band.

To further increase the dimensionality of the data input to MLC, a nine-band image was created using these three texture bands, the four original Ikonos bands, the Normalized Difference Vegetation Index (NDVI), and Chlorophyll Index (CI) (Kanemasu, 1974). The latter two have greater ability than the raw bands and other vegetation indices in separating the more vigorous evergreen forest from partially senescent grass, shrub, and deciduous plantation on dry season imagery in Hong Kong (Nichol and Lee, 2005). However, although these procedures resulted in some improvement in accuracy, the results were well below the minimum acceptable accuracy standard of 80 percent, and it was recognized that a method for reducing the spectral overlap between classes as well as further reducing the high spectral variation within classes was required.

**Multi-level Object-Oriented Segmentation with Decision-tree Classification (MOOSC)**

The Multi-level Object-Oriented Segmentation with Decision-tree Classification (MOOSC) devised during this study is a suite of existing procedures which groups image pixels into segments at different scales and allocates segments to classes using a decision-tree approach. Image segmentation was implemented using a region-based, bottom-up approach in eCognition® (Definiens, 2004). The input image contained ten bands, including the original four Ikonos multispectral bands, the NDVI and CI, the three texture bands, and a DEM elevation band. Pixels were grouped into segments at five levels, based on homogeneity and heterogeneity of color, shape, compactness, smoothness, and scale, and the minimum polygon size was approximately 150 m². In this study, an interactive approach was used to investigate the appropriate settings for the parameters by visual comparison with the air photos. The method of allocating segments to classes is similarly interactive in that thresholds are applied to the ten bands by examination of training area statistics at each level (Figure 3). For example, at the lowest level (Level 1) of the decision tree, the MLC class statistics were examined to determine the threshold in the NIR band to separate land from water. Thus, since the branches of the tree were constructed interactively at each level, there was no redundancy in the tree structure.

At level 3, the chlorophyll index, a ratio of the red and green bands (Kanemasu, 1974) was found to be suitable for the threshold placement between the senescent herbaceous (grass) and woody vegetation classes. Additionally, two morphological operators, elevation and size, were introduced to eliminate some remaining spectral overlap between the darkest areas of lowland forest in terrain shadow (S in Plate 1b), and deciduous plantation (D in Plate 1b), the latter having very low NIR response due to leaf loss. The overlap was due to the inability of the illumination correction algorithm to address areas of absolute shadow in the terrain model of this wintertime image. Such areas have a cos(θ) value of zero and cannot be corrected. This in turn leads to the failure of the NDVI threshold condition in the decision tree classifier which is used to separate evergreen forest from deciduous plantation. Since the misclassified forest segments are much smaller than the plantations, and plantations do not occur above 600 m, they were re-allocated to forest (Plate 1c) using both a size and an elevation threshold. The DEM was also used at level 4 to separate montane forest (above 600 m) from lowland forest. Level 4 distinguishes between the three arboREAL habitats (Figure 3) and the only remaining unclassified area corresponded to the transition zone between grassland and shrubland, which is situated on upper slopes above forest and below the summit grasslands.

**Fuzzy Boundary Placement by Segment Unmixing**

Using the CI band, grassland and forest occur at the extreme ends of a spectrum representing ecological succession from grass, through shrub to forest. This transition can be seen clearly on the air photos (Plates 1c and 1d). Due to the
wildlife importance of shrub succession in grassland (Dudgeon and Corlett, 2004), it was decided to use this band, to determine the thresholds for an additional class, shrubby grassland having a 25 percent proportion of shrub within grassland. The threshold between grassland and shrubby grassland was computed theoretically using pure forest and grassland endmembers taken from training areas on the image. The 4 m pixel size of Ikonos facilitates this, as pure pixels representing the endmembers are available at this resolution. Thus, for example, the CI value of a segment containing 75 percent grass and 25 percent forest, computed from the weighted endmember mean values is 1,367, and visual comparison with the air photos confirmed it to be realistic (Plate 1d).

**Results**

The aerial photo mapping achieved very high overall accuracy of 95 percent (Kappa = 0.93), which is probably a conservative estimate due to the sub-optimal location of the field GPS points near habitat boundaries. In fact, during the study it became clear that the aerial photographs, on which even small shrubs could be identified, gave better visualization of habitat boundaries than fieldwork, due to the obstructed viewing perspectives of fieldwork in the steep terrain, and the fuzzy nature of many boundaries, which require a large field of view. The much higher accuracy obtained than previous air photo mapping projects (Ashworth et al., 1993; Mehner et al., 2001) is not surprising in view of the high quality of the air photo cover, the use of the digital orthophoto as the mapping base, expertise, and the 100 days taken for the interpretation and mapping.

Of the automated methods, the MLC classified image obtained a low accuracy of 66 percent due partly to high within class variability typical of VHR sensors (Hay et al., 2001; Pekkarinen, 2002; Wulder et al., 2004). This can be seen on Plate 2a where there are many isolated “salt and pepper” pixels within homogeneous forest tracts. Additionally, areas of lowland forest (dark green) are incorrectly allocated to the class deciduous plantation (turquoise). This confusion between the darkest areas of lowland forest and deciduous plantation is explained above. Much of the “salt and pepper” variability was eliminated by the addition of texture to MLC (Plate 2b) using a 3 x 3 (i.e., 12 m) window size. The window size was based on observed scale lengths of 11 to 13 m for grassland, 14 to 15 m for plantation, and 13 to 16 m for forest from the Moran’s I assessment. The texture Mean function was particularly effective for distinguishing grassland and deciduous plantation from lowland forest (LF) on Plate 1d; the latter (see deciduous plantation (D) on Plate 1b, and forest and shrub, the former two being much smoother than grassland. The threshold between grassland and deciduous plantation from lowland forest was computed theoretically using pure forest and grassland endmembers taken from training areas on the image. The 4 m pixel size of Ikonos facilitates this, as pure pixels representing the endmembers are available at this resolution. Thus, for example, the CI value of a segment containing 75 percent grass and 25 percent forest, computed from the weighted endmember mean values is 1,367, and visual comparison with the air photos confirmed it to be realistic (Plate 1d).

**Discussion**

All the methods used in the study to classify Ikonos images achieved higher accuracy than a previous study using medium resolution sensors. However, although the addition of texture to MLC was able to eliminate much of the “salt and pepper” variability in the pixel-based classification, it was unable to reduce the spectral overlap between classes. The accuracy level of 74 percent (Kappa = 0.7) accorded generally with the 60 percent forest and 80 percent grassland accuracy obtained for medium resolution sensors at 1:10,000 scale, achieved by Mehner et al. (2004). The superiority of MOOSC over the pixel-based classifiers is due to the reduction of intra-class variation using segmentation, as well as the ability to incorporate ancillary data into the decision-making process. Additionally, the decision tree method used to classify the segments performs well because spatial and spectral variability is progressively eliminated leaving the most difficult classes to be examined at higher levels using more sensitive discriminating parameters.

The semi-automated approach of MOOSC, requiring operator intervention at each level to identify the relevant discriminating parameters, appears more successful than fully automated techniques such as those used by Bock et al. (2005) and Kobler et al. (2006). This may be because natural habitats, especially in rugged terrain, are infinitely variable and cannot be identified with a rule-based approach. Thus, the USGS (2006) states “vegetation mapping requires . . . considerable ecological knowledge of the area to be mapped, including the ability to identify . . . vegetation types, and the relationship of these types to . . . topographic gradients within the mapping area.” The need for operator intervention however, does not compromise the transferability of MOOSC to other study areas, since the interactive approach to setting the segmentation criteria followed by operator decisions, is not different from the approach used in so-called automated methods of supervised and unsupervised classification. All are study area specific and interactive. As a complete habitat mapping methodology, MOOSC works well and is still only approximately one third of the cost of manual, aerial photo-based mapping. Since the aerial photo cover is actually cheaper than Ikonos, the difference in cost is due to the much
Plate 2. (a) Extract of MLC classified image showing many “salt and pepper” pixels, (b) Extract of MLC with texture classified image, showing fewer “salt and pepper” pixels, and (c) Extract of MOOSC classified image.

Segments are unquestionably more effective than pixels for fuzzy boundary placement due to the patchy nature of shrub cover within grassland. The boundary positions of shrubby grassland in automated mapping are dependent on the mapping scale, resolution, and segment size. However, the accuracy of the endmember thresholds for allocating segments is difficult to verify due to the lack of distinct boundaries in the field. Accordingly, the majority of the inter-class confusion of the MOOSC method is observed at level 5, and occurs between the transitional classes of grass, shrubby grassland, and shrub. In spite of these uncertainties due to the fuzzy nature of the boundary, the grassland class appears to be over 90 percent accurate, and shrubby grassland and shrub classes well over 80 percent. As with the MOOSC methodology as a whole, the advantage of using segments and endmembers for greater manpower required for the manual method compared with the semi-automated MOOSC method. Moreover, the time-cost advantages of MOOSC would increase with increasing study area size, since the individual aerial photos to be georeferenced, mosaiced, and stereoscopically examined would not be matched by any significant increase in the number of Ikonos images to be processed.
boundary placement lies in their objectivity, such that the same criteria and spectral thresholds may be used in repeat studies to identify ecosystem change.

Conclusions
This study demonstrates improvements in both cost and accuracy for habitat mapping which are an order of magnitude higher than previous similar projects in Hong Kong, and reflects the state of the art in satellite image technology and methodology. Mehner et al. (2004) conclude that VHR sensors such as Ikonos can provide a useful tool, offering the potential for mapping upland vegetation in UK at the same mapping scale as this project, i.e., 1:10 000. The results presented here suggest that the MOOSC method, based on rigorous exploitation of the spatial and spectral characteristics of Ikonos multispectral imagery may be used to replace traditional manual interpretation, at a level of accuracy far exceeding US vegetation mapping standards. This high level of accuracy has been achieved in a challenging environment, namely using wintertime images in mountainous terrain. The MOOSC method is flexible enough to be applied to any study area, since it accommodates an interactive approach to the placement of spatial and spectral thresholds. Moreover, MOOSC is more repeatable than manual techniques, and the same image-based thresholds can be used at a future date.
In view of the greatly reduced cost, repeatability, and similar accuracy to manual techniques obtained from the MOOSC methodology, the results strongly recommend VHR multispectral satellite imagery, such as Ikonos, as the best choice for habitat mapping at 1:10 000 scale.

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