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# Shape and resolution: quantifying feature morphology change due to coarsening spatial resolution using UAV-based images from vertical transects

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## Abstract

Aside from tone or colour, shape is one of the most readily utilized characteristics to interpret remotely sensed imagery. As spatial resolution is coarsened, the level of observable spatial detail diminishes, thus the shapes of features become less distinct. This study controlled the observation platform, a Tetracam ADC snap multispectral camera mounted on a Phantom 2 quad-copter, to collect images along vertical transects. This design simulates continuously coarsening spatial resolution as the aircraft ascends, while maintaining consistent imaging parameters. Vegetation visible on all scenes was analysed using common shape characterizations. Scaling relationships were assessed between original shape complexity and spatial resolution (a proxy for scale). Initial results show strong scaling relationships at ultra-fine scales but an interesting area of stability which, if repeatable, could have important implications for the use of UAVs in environmental research.

## 1. Introduction

The characterization and comparison of spatial pattern characteristics or landscape morphological elements are sectors of GIScience that intersect with mathematics and landscape ecology, and have been developing for several decades (Gardner *et al*. 1987; Haines-Young and Chopping 1996; Uuemaa 2009). Numerous studies span the breadth of such inquiries, ranging from studies of land cover change (Linke *et al*. 2009) to assessing habitat suitability (McAlpine and Eyre 2002). While computing a suite of metrics is facilitated by readily accessible software (Baker and Cai 1992; McGarigal and Marks 1995; Vogt *et al*. 2007), many redundancies have been identified (Riitters *et al*. 1995) and limitations explicitly characterized that limit the inference that can be drawn from such metrics (Remmel and Csillag 2003). Scale effects have been tested by manipulating landscape extent and spatial resolution, but these generally rely on resampling or the use of multiple platforms of data (e.g. Saura 2002; Baldwin *et al*. 2004).

This study focuses on the characterization of planar shape, a single aspect of the broader collection of pattern metrics, with respect to scale. Shape provides the ability to characterize and discriminate individual landscape elements (Zhang and Atkinson 2016), rather than summarize landscape-wide patterns. Scaling analysis was applied to data obtained from a consistent platform, such that resampling or sensor substitution did not introduce spurious relationships and uncertainty that make interpretation more complex. By manipulating a single variable (spatial resolution) of a digital image while maintaining all camera, timing, and environmental conditions constant, we explored the effect of spatial resolution on the quantification of patch shape directly. This differs from Saura and Carballal (2004) where scale was kept consistent and multiple indices were applied to measure shape (at the class level) to assess the indices' effectiveness.

Our research question asks: does spatial resolution have a significant effect on measuring patch shape? Obviously there is an effect once spatial resolution becomes coarse relative to the local detail being depicted, but we seek to characterize the functional relationship between spatial resolution and shape measurement for selected phenomena captured on images. We hypothesize that knowing the form of this function will allow improved selection of spatial resolutions for the detection, mapping, and analysis of shapes in landscapes.

## 2. Methods

The study was conducted at an urban parkland meadow consisting of grasses, shrubs, and scattered trees (approximate centroid: 45° 24' N, 75° 45' W) in Ottawa, Ontario, Canada. The site permitted easy access and an ability to perform field validation to ensure feature identification accuracy. The species and communities were not of interest as much as the ability to observe features at the ground level and also from airborne perspectives.

Data were acquired with a Tetracam ADC Snap multispectral camera sensitive to the green, red, and near infrared regions of the electromagnetic spectrum. The 90 g camera was nadir mounted to a Phantom 2 quad-copter unmanned aerial vehicle (UAV), and powered by the UAV battery (image at http://bit.ly/2aLycMl). A benefit of the fixed-rotor UAV is that it can be flown directly upwards by providing additional upward thrust. This allows vertical transects, rather than just horizontal, allowing us to manipulate spatial resolution while repeatedly imaging a common ground area. The flight platform is customized with a ground pilot display (iOSD mini) showing flight telemetry along with a real-time view of the image being acquired by the multispectral camera. The telemetry allowed us to position the flight platform directly above the object of interest and ensured that we acquired imagery at desired altitudes. We set the imaging interval at 3 seconds and controlled the rate of ascent such that we obtained multiple views of the same ground feature.

Prior to flying the vertical transects over prominent features in the study area, a series of polished metal salad bowls were placed upside-down in the field to serve as ground control points. Since the bowls did not move and were visible in each image, they were used to simplify the relative geo-registration of images centred over the feature of interest. The range of altitudes traversed resulted in images having spatial resolutions ranging from 5.6 mm (at 10 m altitude) through 5.1 cm (at 90 m altitude); the coarse maximum corresponds to the legal flying height restriction, not the limits of the imaging system.

In this initial study, we concentrated on a single feature of interest (shrubs), binary-classified (ISODATA clustering, 16 initial clusters, background image manually aggregated), at the centre of the field of view for each vertical transect. Here we present the results from the first vertical transect we have analysed, providing a suite of metrics that characterize the shape of the feature: area, perimeter, and corrected perimeter-to-area (cPA) ratio (relates the shape's perimeter:area to that of a perfect circle; Farina 2006: 321). The results are plotted relative to the spatial resolution to obtain functions relating scale to shape.

## 3. Results

Scaling relationships were markedly different at coarser vs. finer resolutions. At ultra-fine resolutions (less than 25 mm) there were strong scaling effects on the shape metrics (Fig. 1; full tabular results including image resolutions at http://bit.ly/2aMnHra). At elevations close to the ground (below 40 m altitude), and therefore the highest image resolutions, the detected shrub perimeter followed a fairly well defined linear scaling relationship, with higher perimeter detected at finer resolutions; however, the area of the detected shrub fluctuated as contiguous portions of the shrub canopy as detected by ISODATA clustering became detached and re-attached (Fig. 2). As a result, the cPA shape index also had a linear trend towards higher ratios at finer resolutions, but with progressively increasing scatter. Once altitude reached about 40 m, with spatial image resolution increasing ~25 - ~55 mm, this scaling relationship levelled off. For at least the aspects of shape studied here, there appears to be no scaling relationship within that range of resolutions.

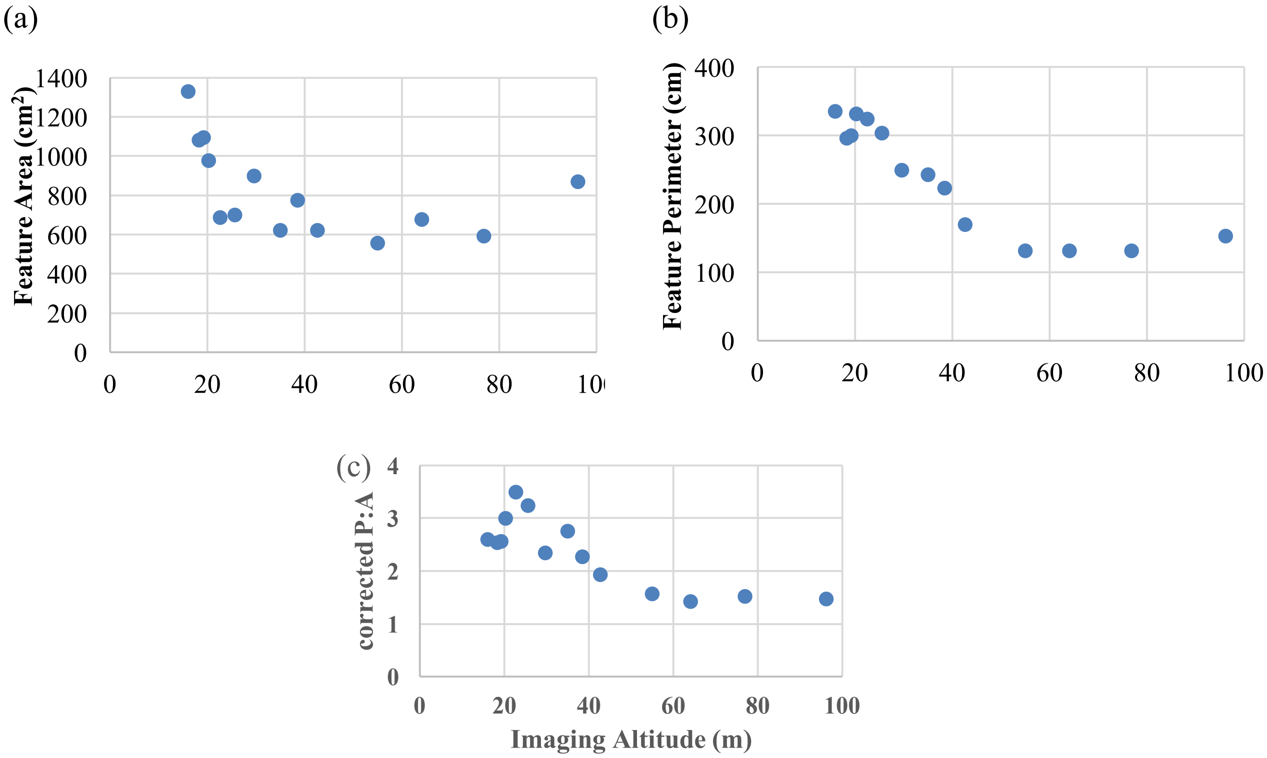

**Figure 1 (a) shrub feature area, (b) perimeter, and (c) cPA, with respect to imaging altitude along a vertical transect.**

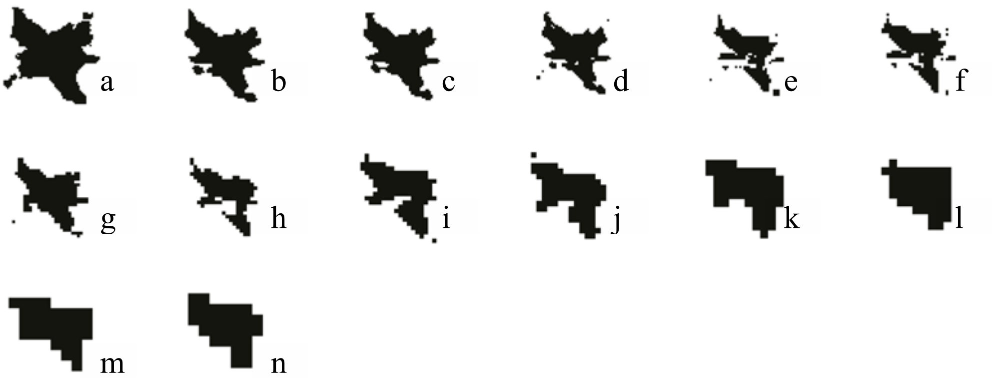

**Figure 2. Shrub representations at different spatial resolutions ranging from 9.13 mm (a) through 54.75 mm (n).**

## 4. Discussion and Conclusions

Although these are clearly preliminary results, given the novel yet increasingly feasible range of applications provided by the rapidly developing UAV industry, we wish to rapidly disseminate these observations to help spur complementary research. The sharp changes in the observed scaling relationships, and particularly the observation that shape descriptors remained stable through a range of resolutions, could have strong implications. Through spatial resolutions of ~9 to ~25 mm, the scaling behaviour of the shrub's perimeter is reminiscent of the infinite coastline example often used to illustrate fractal theory (Mandelbrot 1967). However, across a fairly large range (in terms of flight planning) of spatial resolutions (25-55 mm), there was little change in the calculated metrics.

The generality of these observations needs to be tested, both across other image objects within our study site, and in other contexts (are the slopes and asymptotes of the scaling relationships consistent?). We plan to repeat the analysis across other plant objects in the imagery to develop confidence intervals for our scaling relationships, and to compute *ShrinkShape* decompositions (Remmel 2015). The decomposition will conduct iterative shrinking of planar shapes interspersed with the measurement of the remaining area and perimeter until the shape becomes extinct due to shrinking, and extract MSPA morphological element summaries (Vogt *et al*. 2007). Conducting similar analyses using other physical environments, platforms, and extracted measures will help us understand the potential for exploiting the much higher, and controllable, spatial resolutions offered by UAV technology.

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