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# Resolution dependent errors in remote sensing of cultivated areas

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**Abstract**

Remote sensing has become a common and effective method for estimating the areal coverage of land cover classes. One class of particular interest is agriculture as area estimates of cultivated lands are important for purposes such as estimating yields or irrigation needs. The synoptic coverage of satellite imagery and the relative ease of automated analysis have led to widespread mapping of agriculture using remote sensing. The accuracy of area estimates derived from these maps is known to be related to the accuracy of the maps. However, even in the situation where the map is very accurate, errors in area estimates may occur. These errors result from the behavior of the distribution of subpixel proportions of cultivated areas, and how that behavior changes as a result of sensor spatial resolution and class definitions. The sensitivity of estimates of cultivated areas to sensor spatial resolution and to the choice of threshold used to define cultivated land is explored in six agriculturally distinct locations around the world. Using a beta model for the distribution of subpixel proportions that is parameterized using variograms, it is possible to model the distribution of subpixel proportions for any spatial resolution. When the spatial resolution is small with respect to the spatial structure of the landscape (as measured by the variogram range) use of any class definition threshold produces an estimate very close to the true area coverage. On the other hand, as the resolution becomes coarse in relation to the variogram range, the subpixel proportions are no longer concentrated at the extremes of the distribution and the difference between the estimated and the true area has greater sensitivity to the selected threshold used to define classes. Thus, for the cases examined here, *both* the resolution and the class definition threshold have a strong influence on area estimates. The spatial resolutions where errors can be large depend on landscape spatial structure, which can be quantified using variograms. The net effect is that for the same spatial resolution, some places will exhibit much larger errors in area estimates than others. For the site in the Anhui province of China, where agricultural fields are very small (0.07 ha on the average), area estimates are highly sensitive to class definition thresholds even at the relatively fine resolution of 45 m. Conversely, in California (USA) spatial resolutions as coarse as 500 m can be used to reliably estimate cultivated areas. Results also suggest that the proportion of the total area that is cultivated significantly influences the accuracy of area estimates. When the area proportion is low, the class definition threshold must also be low to achieve an accurate area estimate. Conversely, in areas dominated by agriculture, a very stringent class definition of cultivated lands is required for accurate area estimates. While explored in the context of estimation of cultivated areas, the findings presented here are generic to the problem of area estimation using remote sensing.


*Keywords:* Agriculture; Variogram; IKONOS

## 1. Introduction

Remote sensing is used in a variety of ways to study our environment. One common approach is to measure an amount, or area, for a thematic category. Simple examples could include measuring the area of forest in a state or country, or the surface area of lakes. Remote sensing is particularly well suited for the estimation of areas, as remote sensing images typically provide synoptic coverage of the areas of interest. There are two common approaches to the area estimation problem with remote sensing. One approach estimates fractions of a thematic category of interest for each pixel (Hansen et al., 2002; Quarmby et al., 1992). The most difficult part of this approach is the accurate recovery of fractions of the thematic field. Nevertheless, given the improved spectral capabilities of today's sensors as well as improvements in subpixel mapping methods such as spectral mixture analysis and the development of non-parametric tools such as neural networks or decision trees (Hansen et al., 2002; Liu & Wu, 2005), area estimation via thematic fractions is becoming more common.

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A second approach for estimating the area of a surface feature is to make a thematic map through image classification and simply multiply the area of the pixels with their number in a particular class. An immediate issue concerning area estimates via image classification is thematic map accuracy. The assumption is that the map is accurate or the errors between classes are such that they cancel each other. Recognition of the importance of thematic map accuracy and its effect on area estimates is well established in the literature and methods for adjusting the area estimates of map classes based on accuracy assessments are commonly used (Card, 1982; Czaplewski & Catts, 1992; Hay, 1988). While these approaches improve the accuracy of area estimates, there are also more subtle effects that can introduce error in area estimates derived from thematic maps. In particular, the fact that all pixels in an image may not be composed entirely of a single class can introduce uncertainty into area estimates. The existence of mixed pixels and the problems they cause for automated image classification have long been noted (Atkinson & Curran, 1995; Jupp et al., 1979; Markham & Townshend, 1981; Turner et al., 1989). Even with accurate land cover maps there is still the possibility of errors in area estimation (Moody & Woodcock, 1994; Pax-Lenney & Woodcock, 1997). This problem is most immediately noticeable at coarse resolutions, and there have been approaches developed to improve area estimates from coarse resolution imagery based on calibrations derived from finer spatial resolution data (DeFries et al., 1999; Mayaux & Lambin, 1995; Moody & Woodcock, 1996). One note is that throughout this paper we use the term “accurate” for land cover classification if a pixel is assigned to the dominant land cover occurring within the pixel, as this is the accepted norm for accuracy assessment of thematic maps. However, it is worth mentioning that recently a different view of accuracy has been presented by Latifovic and Olthof (2004), in which only accurate representation of the mixes of land covers within individual pixels constitutes an accurate answer for a pixel.

Beyond the issue of accurately classifying pixels in images, mixed pixels also pose problems for the question of area estimation. Underlying the image classification approach to area estimation is the question of class definition: classes must be defined based on the amount of the class that is required to be present, or a threshold. Consider the issue of trying to estimate the cultivated area in an agricultural setting where cultivated fields are smaller than the spatial resolution of the observing sensor. Here, both cultivated and uncultivated areas (e.g. roads, dwellings, irrigation ditches) are included in a pixel classified as *agriculture* or *cropland*. In this situation the area of the class *agriculture* may not be an accurate estimate of the cultivated area. In agricultural settings, the amount of uncultivated area has been reported to vary from 10 to 40% (Crapper, 1980; Fang, 1998; Frolking et al., 1999; Gonzales-Alonso et al., 1998; Okomato & Fukuhara, 1996). In other situations the errors in areal estimates of thematic categories have been even worse. For example, differences on the order of 40 to 50% have been reported for estimates of burnt area derived from the Advanced Very High Resolution Radiometer (AVHRR) (Setzer & Pereira, 1991) and Moderate-Resolution Imaging Spectroradiometer (MODIS) (Hlavka & Dungan, 2002) as well as for various other land cover classes in coarse resolution maps when compared to estimates from Landsat (e.g. Moody & Woodcock, 1994). These examples highlight the issue that beyond accurate image classification, the accuracy of area estimates with remote sensing also depends on the interaction between the sensor spatial resolution and the size and spatial arrangement of landscape elements. Hence, the spatial resolution of the sensor and in conjunction with the spatial properties of the landscape need to be considered in area estimation problems.

Although there is now more choice of remote sensing measurements from a wider variety of sensors than at any time in the past, the selection of a sensor for a particular application is still primarily dictated by the geographic extent of the study. For large areas such as continents, the primary sources of data have typically been coarse resolution sensors such as AVHRR, MODIS and SPOT VEGETATION with wide area coverage (DeFries et al., 1999; Friedl et al., 2002; Frolking et al., 1999; Roy et al., 2002; Zhan et al., 2002). Similarly, data from high spatial resolution sensors like Landsat and SPOT HRV have been used in support of local to regional scale applications that require increased spatial detail (Kasischke et al., 2004 and references therein). What is less known, however, are the magnitude of errors incurred in estimates of the area of a thematic category of interest (or a class) as a function of the spatial resolutions of different sensors. Previous studies show that while coarsening the spatial resolution clearly leads to a loss of spatial detail (Woodcock & Strahler, 1987), the magnitude of errors in area estimation with increasingly larger pixels is dependent on the spatial structure of the landscape (Moody & Woodcock, 1994; Turner et al., 1989). To highlight this point, consider again an agricultural landscape. In the US, where cultivated fields tend to be large and homogeneous over great distances (Pitts & Badhwar, 1980), area estimates made with coarse resolution imagery such as AVHRR or MODIS may be quite accurate. In contrast, agricultural area estimates with even fine resolution data such as Landsat in places with very small cultivated fields (e.g. China) may lead to unacceptable errors. This situation may also be true for a variety of other landscapes and sensors.

## 6. Summary and conclusions

Area estimation is often taken for granted in remote sensing, when in fact large errors in area estimates for classes are possible even when based on accurate thematic maps. These errors tend to be worse when the size of the fields is larger than the size of the pixels in the image and all pixels become mixed pixels. In these situations, the magnitude of the problems also depends on the subpixel proportions used to define class memberships and the proportion of the class in the overall study area. The use of the beta model for the distribution of subpixel proportions provides a powerful framework for studying problems of area estimation in remote sensing. Indicator variograms of the class of interest (cultivated fields in this case) prove a useful way of parameterizing the beta distribution. These variograms are also helpful indicators of the size of agricultural fields. The practical implications of the results of this study include (1) guidance on methods for selecting spatial resolutions of sensors for applications focused on area estimation, and (2) guidance regarding the selection of thresholds in subpixel fractions used for the definition of classes. While the examples and context used in this study are from agriculture, the findings with regard to the effects of spatial resolution and scene structure are generic and applicable to many other application domains of remote sensing.