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How much can natural resource inventory benefit from finer resolution auxiliary data?

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ABSTRACT

For remote sensing-assisted natural resource inventories, the effects of spatial resolution in the form of pixel size and the effects of subpixel information on estimates of population parameters were evaluated by comparing results obtained using Landsat 8 and RapidEye auxiliary imagery. The study area was in Burkina Faso, and the response variable of interest was firewood volume (m^3/ha). A sample consisting of 160 field plots was selected from the population following a two-stage sampling design. Models were fit using weighted least squares; the population mean, μ, and the variance of the estimator of the population mean, $V(\hat{\mu})$, were estimated using two inferential frameworks, model-based and model-assisted, and compared. For each framework, $V(\hat{\mu})$ was estimated both analytically and empirically. Empirical variances were estimated using bootstrapping that accounted for the two-stage sampling. The primary results were twofold. First, for the effects of spatial resolution and subpixel information, four conclusions are relevant: (1) finer spatial resolution imagery indeed contributed to greater precision for estimators of population parameter, but despite the finer spatial resolution of RapidEye, the increase was only marginal, on the order of 10% for model-based variance estimators and 36% for model-assisted variance estimators; (2) subpixel information on texture was marginally beneficial for inference of large area population parameters; (3) RapidEye did not offer enough of an improvement to justify its cost relative to the free Landsat 8 imagery; and (4) for a given plot size, candidate remote sensing auxiliary datasets are more cost-effective when their spatial resolutions are similar to the plot size than with much finer alternatives. Second, for the comparison between estimators, three conclusions are relevant: (1) sampling distribution for the model-based $\hat{V}(\hat{\mu})$ was more concentrated and smaller on the order of 42% to 59% than that for the model-assisted $\hat{V}(\hat{\mu})$, suggesting superior consistency and efficiency of model-based inference to model-assisted inference; (2) bootstrapping is an effective alternative to analytical variance estimators; and (3) prediction accuracy expressed by RMSE is useful for screening candidate models to be used for population inferences.

1. Introduction

The state of ecosystems across Africa including vegetation trends and land cover is still little known, but is particularly important in understanding land degradation processes, predicting changes in climate and improving land management (Vågen et al., 2015). Baseline inventories of ecosystem properties may allow for a proper assessment of landscape performance and prediction of change over time. In West Africa, the increasing consumption of fuelwood has been considered a cause of forest degradation and deforestation in the region which, in return, is likely to make energy sources scarcer, more expensive as well as cause a deterioration in ecosystems and greater vulnerability to climate change (Arevalo, 2016; Papillon et al., 2006; Puentes-Rodriguez et al., 2017). Energy in Sub-Saharan Africa is significantly more expensive than in other parts of the world, and approximately 80% of all residents depend on fuelwood as their main energy source, mostly firewood and charcoal with a combustion efficiency less than 30% (UNDP, 2010). Burkina Faso has a very large annual population increment and small community development indices, is ranked among the most vulnerable countries to climate change, and faces energy crises for which fuelwood can be expected to play a crucial role (Arevalo, 2016). With the launch of the Reducing Emissions from Deforestation

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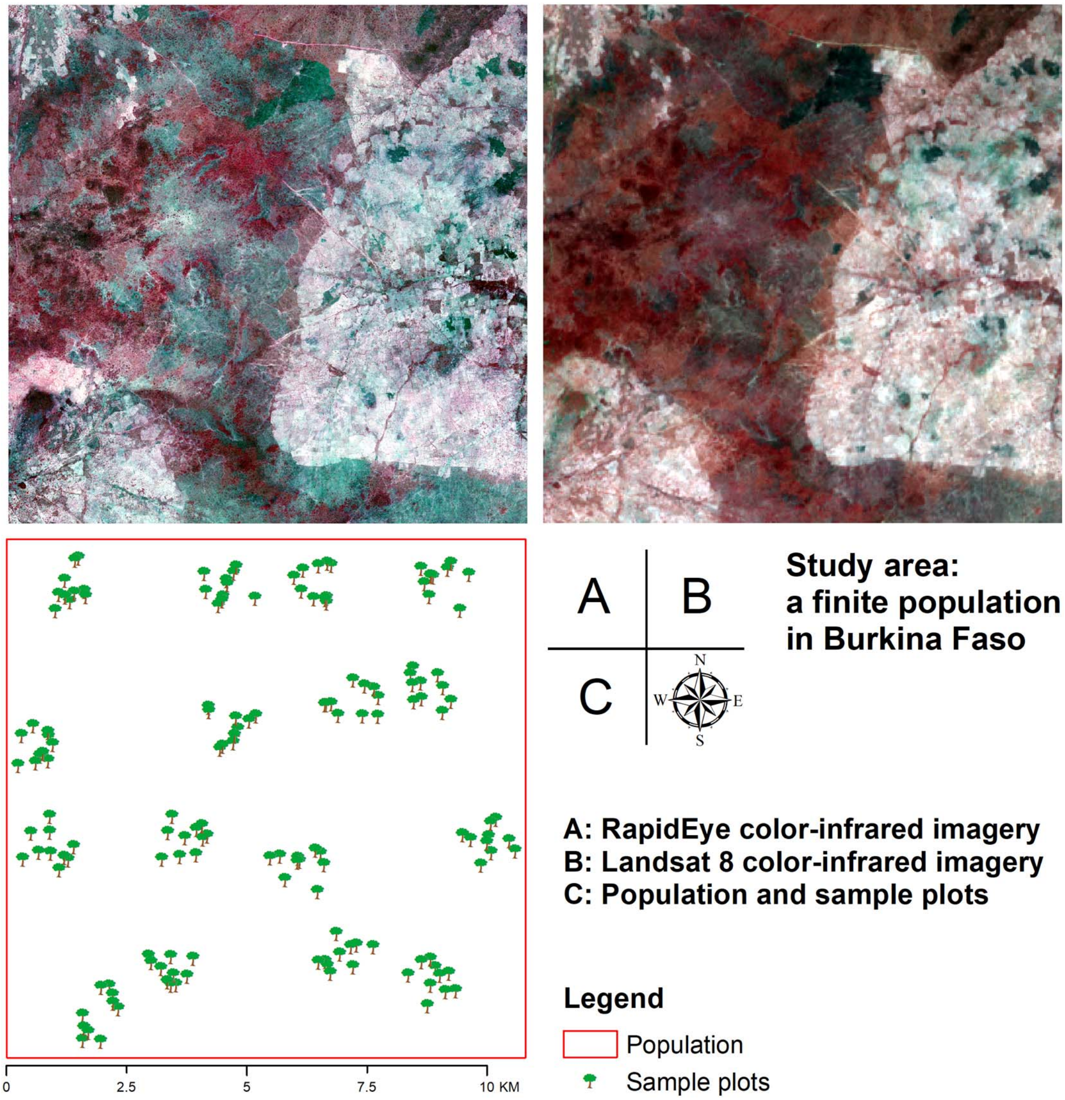

Fig. 1. The study area and the sample plots in the rural commune of Kou in south-eastern Burkina Faso.

and Forest Degradation (REDD+) program in 2010, the government of Burkina Faso elaborated strategies for environmental protection, forestry and climate change adaptation and mitigation, and an accompanying investment plan for 2008–2018 that relies on recurrent inventories providing accurate and reliable information about the status of ecosystems (MEDD, 2012).

Traditionally, large-scale inventory programs use field surveys based on probabilistic sampling designs that support estimators with sufficient precision (Tomppo et al., 2010). This design-based inference is free from assumptions regarding the structure of the population, because it is based on the distribution of all possible estimates permissible under the strict terms of the sampling design (Cochran, 1977). However, because the desired properties of design-based estimators rely on sufficiently large sample sizes, they are apt to become unaffordable and relatively less cost-efficient; conversely, reduced sample sizes risk failure to satisfy precision criteria. This dilemma would hinder developing countries from implementing repetitive inventories to regularly update the status of ecosystems and natural resources as is required today for understanding land degradation processes, predicting changes in climate and improving land management (MEDD, 2012).

Remote sensing-assisted Inventories have become increasingly popular. In particular, remotely sensed auxiliary data that are correlated with attributes of interest facilitate use of model-based inference (Gregoire, 1998). Model-based inference relies on a model as the basis for constructing inferences in forms such as confidence intervals for the population parameters (Cassel et al., 1977). The finite population is regarded as a realization of a random process called a superpopulation, and every finite population is seen as a sample of the infinite superpopulation (Särndal, 1978). The superpopulation is defined by the superpopulation model wherein the remotely sensed auxiliary information enters as independent variables. Properties of a model-based population parameter estimator (or predictor considering that the population parameters are random) are deduced conditionally with respect to the observed sample and the stipulated model, not the sampling design. A major concern with model-based inference is the potential for serious bias in the population parameter estimator if the presumed or stipulated model is misspecified (Hansen et al., 1983; Royall and Herson, 1973; Valliant et al., 2000). As an alternative to model-based estimators, model-assisted estimators also use models and auxiliary information to improve estimator precision (Baffetta et al., 2009). However, inference validity is contingent on probabilistic samples, so model-assisted estimators are still design-based.

The finest possible data recorded by pixels are constrained by the spatial resolution of a spectral remote sensing sensor. Each pixel represents a measured surface reflectance value, and the detail discernible in imagery depends on the spatial resolution of the spectral sensor. For a homogeneous feature to be correctly predicted, its size usually should not to be smaller than the pixel size, or the prediction is