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| Incorporating Spatial Heterogeneity into Model-Assisted Estimator to Improve  Small Area Estimation |
| Precise small area estimation of forest characteristics, such as forest area, forest biomass, forest volume and carbon are often difficult because of limited sample sizes. To increase the precision of estimates, model-assisted regression estimators which take advantage from remote sensed auxiliary data are increasingly used for the USDA Forest Service Inventory and Analysis programs. Spatial heterogeneity, also known as spatial nonstationary, is a fundamental characteristic for geographically spatial populations, however, randomly selected field plots using quasi-systematic sampling from geographical forest population cannot guarantee a “spatially balanced” distribution across the study area, and spatial heterogeneity in model residuals would be a potential problem when building regression models using sample data in model-assisted estimator. There are numerous area-level approaches that account for spatial heterogeneity, for example, spatial Fay–Herriot models provide a smooth spatial adjustment by including both the mean-zero spatial random coefficient and spatial random error, and this area-level model has been applied to forest biomass and volume estimation. In contrast to the situation with area-level models, far fewer studies have evaluated or implemented unit-level models that account for spatial heterogeneity in model-assisted estimator in small area estimation of forest characteristics.  Geographically Weighted Regression (GWR) is an effective way to deal with the spatial heterogeneity of model residuals and model coefficients. GWR was first introduced in geography to model variations in relationships between variables over space and it has been widely used in the fields of geography and environment. GWR is an extension of ordinary least squares regression but allows the model relationships to vary across space based on detecting where locally weighted regression coefficients deviate from global coefficients. This study introduces and develops a unit level GWR model-assisted estimator to estimate forest characteristics in small area estimation. The estimators were evaluated using Monte-Carlo simulation applied to both constructed populations and operational FIA sample data with full coverage of area remote sensing auxiliary data across the state of Virginia. Variances and standard errors of the estimates from GWR model-assisted estimator are compared with the variances and standard errors of the estimates estimated from Horvitz-Thompson estimator, poststratified estimator, and generalized regression estimator under the design-based inference. For the constructed populations, the GWR model-assisted estimator has smaller variances and standard errors than other estimators in populations with moderate or strong spatial variation. For operational FIA applications, GWR model-assisted estimator provided much smaller variances and standard errors than Horvitz-Thompson estimator, and the variances and standard errors are smaller than model-assisted estimator use generalized regression model. GWR model-assisted estimator provides an efficient way to improve the precision of the estimates through improving local predictions of target variable from the regression model. With the efficiency and simplicity of GWR model, the proposed GWR model-assisted estimator could be served as a practical method to estimate the forest characteristics in small area estimation. Further study is needed to evaluate the efficiency of other model-assisted estimators using spatial models. |