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A design-based approach for mapping the diversity of forest attributes

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Abstract. *Forest attributes such as volume or basal area are concentrated at tree locations and are absent elsewhere. Therefore, it is more meaningful to consider the amount of forest attributes at a pre-fixed spatial grain, within regular plots of pre-fixed size centered at the points of the study area. In this way, also the diversity of attributes within plots can be considered and quantified by suitable indexes, giving rise to a diversity surface defined on the continuum of points constituting the area. We analyze the estimation of diversity surfaces when a sample of plots is selected by a probabilistic sampling scheme and diversity within non-sampled plots is estimated using an inverse distance weighting interpolator. We discuss the design-based asymptotic properties of the resulting maps when the survey area remains fixed and the number of sampled points increases.*
Because diversity surfaces share suitable mathematical properties, if the schemes adopted to select sample points ensure an even coverage of the study areas avoiding large portions of non- sampled zones, it can be proven that the estimated maps approach the true maps.

Keywords. *diversity maps, inverse distance weighting interpolator, design-based consistency, spatial simulation, case study*

1 Introduction

Spatially explicit estimates are needed in many environmental and ecological applications for obtaining the spatial distribution of forest attributes within the area of interest [2]. These attributes, such as volume and basal area, are concentrated at tree locations and absent elsewhere. Therefore, it is more meaningful to consider the amount of forest attributes at a pre-fixed spatial grain, i.e. within regular plots of pre-fixed size centered at the points of the study area, rather than to consider the attribute amounts at single points [4]. In this way, the diversity of these attributes within plots can be quantified by suitable indexes.
Any point of the survey area can be considered as the center of a plot of pre-fixed radius, in such a way that there exists a diversity index value for any point, giving rise to a diversity surface defined on the continuum of points constituting the area. In most cases, the available resources and the continuous nature of the survey area render impossible to completely census the entire region. Therefore, the diversity indexes are recorded only within those plots centered on a sample of points and an estimation criterion is adopted to estimate the index values for those plots centered at non-sampled points, obtaining a wall-to-wall map depicting the spatial pattern of diversity throughout the whole survey area.

2 Design-based prediction

Usually, methods adopted to reconstruct population maps lie in the realm of model-dependent inference, i.e. the sampled sites are held fixed (as if they were purposively selected) and the diversity index values at these sites are supposed to be random variables generated from a continuous spatial process (super-population). Under model-dependent approaches, uncertainty stems from the super-population that has been supposed to generate the surface, conditional on the sampled sites.
However, here we follow an alternative criterion proposed by [1] for attempting the diversity map reconstruction in a design-based framework, i.e. the diversity surface is viewed as constant and uncertainty stems from the probabilistic sampling scheme adopted to select points. It follows that diversity index values at single non-sampled points are estimated by means of a spatial interpolation usually referred to as inverse distance weighting (IDW). The interpolator adopts a weighted average of diversity values recorded at sampled points with weights decreasing with the distance of the sampled points from the point under estimation. The estimation criterion is motivated by the Tobler's first law of geography [3], for which points close in space are more similar than those far apart. It should be noticed that the diversity surfaces under estimation are piecewise Lipschitz functions almost everywhere, a feature of relevant importance for the design-based estimation of these surfaces. Moreover, the asymptotic design-based properties of IDW are derived by [1] as the number of sampled points increases, outlining the conditions ensuring design-based unbiasedness and consistency. An easily computable estimator of the mean squared errors at any points of the estimated surface is adopted. It is worth noting that if the schemes adopted to select sample points ensure an even coverage of the study areas avoiding large portions of non- sampled zones, the estimated maps approach the true maps.
A simulation study on a real population of trees has been performed to estimate the maps of Shannon diversity index of tree stem diameter at breast height, whereas an application of the described method for estimating the map of the basal area diversity in the forest of the Bonis watershed (Southern Italy) has been considered as a case study.

3 Conclusions

Assumptions ensuring design-based asymptotic unbiasedness and consistency of the IDW interpolator of diversity surfaces in environmental studies concern the sampling design to allocate plots on the survey area, the distance function to be used in the interpolation, and the mathematical features of the true diversity surfaces. While the sampling design and the distance function are controllable by the researcher to a large extent, the continuity of the surfaces besides set of measure zero is guaranteed by the nature of these surfaces themselves.
The approach as here applied only exploits geographical distances, while model-based approaches, especially regression kriging, allow exploiting the information provided by various full cover and inexpensive auxiliary variables, usually derived from remote sensing sources. For this reason, our next research goal is to include auxiliary variables in the technique, once again avoiding model constraints and assumptions.

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