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ScienceDirect
Procedia Environmental Sciences 27 (2015) 6 – 9
Procedia Environmental Sciences

Spatial Statistics 2015: Emerging Patterns - Part 2

Spatially Balanced Sampling: application to environmental surveys

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Abstract

Spatially balanced sampling is becoming a popular design for surveys in biological and environmental management. For large scale surveys, where the region of interest is too large to visit every site, a sample is taken from a selection of sites. The process used to select these sites is called the survey design. Spatially balanced designs ensure there is spatial coverage of the entire survey area. The resultant sample should be representative of the population of interest.

One of the first and the most commonly used spatially balanced design is called GRTS (Generalized Random Tessellation Stratified sampling) where sample effort is spread evenly over the target region. The term "spread evenly" in this context means having coverage of survey effort over the region. The coverage from GRTS has a stochastic component rather than a fixed interval, regularly spaced coverage as in a systematic sampling design.

We have extended the idea of GRTS to a new design called Balanced Acceptance Sampling (BAS). The BAS design allows surveys to be balanced in dimensions higher then two (n-dimensional space). Until now, most designs have considered balance in 2-D geographic space. With BAS we can achieve balance in 3-D space (e.g., water bodies in marine surveys), or in higher dimensions. In ecological surveys BAS can be used to ensure balanced coverage over both the geographic space and dimensions related to factors such as ecological threat, conservation status, species population structure, and the time interval of repeat site surveys

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Peer-review under responsibility of Spatial Statistics 2015: Emerging Patterns committee

Keywords: monitoring; survey design; Generalized Random Tessellation Stratified sampling; systematic sampling

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Peer-review under responsibility of Spatial Statistics 2015: Emerging Patterns committee
doi:10.1016/j.proenv.2015.07.108

1. Introduction

Access to quality information about the status of natural systems is a key feature of modern environmental management. Timely, accurate and informative data from field surveys are the key stone of good environmental monitoring and decision making (Lovett et al. [1]).

Environmental monitoring is a very broad practice. It can extend from collecting data to report on changes in a species' distribution associated with a biological invasion, monitoring changes in water and air quality, through to collecting data to assess the impact from a change in government policy. Quality environmental monitoring goes hand in hand with good survey design (Legg and Nagy [2]), and developing efficient and effective surveys for environmental systems is a fast evolving area of statistics.

One principle of survey designs for environmental studies is that a biological characteristic observed in one area is likely to be observed in an adjacent area. For example, the counts of a newly arrived invasive species in a field location will be correlated with the counts in a nearby field location (Grafström et al. [3]) because of the underlying biotic and abiotic processes driving the species' distribution. This feature motivated development of survey designs where the sample is evenly, or near to evenly, spread over the study area. A design that generates samples that are well-spread over the population is termed a spatially balanced survey design.

There are many different methods of spatially balanced survey designs (Wang et al. [4]). The most well known is Generalized Random Tessellation Stratified sampling (GRTS), developed by Stevens and Olsen [5]. In this design an invertible mapping technique is used to transform two-dimensional space into one-dimensional space. Then, a systematic sample is selected along the linear representation. Sampling location geo-references are generated from selecting points at regular intervals in this one-dimensional space (Brewer and Hanif [6]). The one-dimensional space is then mapped back to the two-dimensional original space. By maintaining the spatial properties of the original units, the resultant sample is balanced, with neither no one area being over-represented with high sample intensity nor under-represented with low sample intensity.

The GRTS design (Stevens and Olsen [7, 8, 5]) was first designed for applications to large-scale monitoring and river systems. Since then it has been used in many applications. Some of the most recent examples are in forestry (Ackr et al. [9]), benthic surveys (Dunton et al. [10]), freshwater fish (Rodtka et al. [11]) and air quality associated with coal fires (Engle et al. [12]).

Here we present a new development in spatially balanced sampling where we extend the GRTS design. Our design can be used for environmental surveys where the interest is in dimensions higher than two. The simplest example of this is surveys of water bodies where spatial balance in three dimensions is desirable. Other examples are environmental monitoring where balance is needed in both geographic (two-dimensional) space and across a third (or more) feature, such as a measure related to land status, species vulnerability, or habitat suitability. The other motivation for developing the GRTS design further was to produce a new algorithm for the sample unit selection to improve design characteristics of spatial balance and survey efficiency.

2. Balanced Acceptance sampling

Balanced acceptance sampling, BAS, (Robertson et al. [13]) produces surveys that have the desirable feature of sample units being spread evenly over the design space. The method uses the Halton sequence, a quasi-random number sequence (Halton [14]). In two-dimensional geographic space, Halton points are used to generate the geo-referenced locations of the sample units (starting from a randomly chosen position in the sequence). The design uses acceptance/rejection sampling to select sample units. If a generated sample point is beyond the edge of the sample space the sample unit is rejected, otherwise it is accepted. First order inclusion probabilities can be calculated, or estimated, for the design (a requirement for estimating sample statistics such as the sample variance).

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