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Designing Experiments that Control for Spatial and Temporal Variation

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Abstract

Spatial and temporal variation can cause problems in designing and conducting experiments. An introduction to methods for controlling spatial and temporal variation in ecological experiments is provided in this article. Failure to consider spatial and temporal variation often causes researchers to lay out experiments incorrectly. The challenge is to design experiments that not only reflect the natural variation seen in the field but also control for the variation so that statistical tests have sufficient power.

Spatial variation is usually controlled by grouping observations and treatments into blocks. Blocks can be laid out in a number of ways and Analysis of Variance (ANOVA) approaches to control for block effects are discussed.

The control of temporal variation presents special difficulties because data are often serially correlated and so observations are not independent. Use of intervention analysis and repeated measures analysis of variance to control for temporal variation are discussed. Ecologists have also used experimental designs which are known as BACI designs (i.e., Before-After-Control-Impact design) and can be extended to include multiple control and/or impact sites. Intervention analysis, BACI designs, and their extensions have subtle differences because of different assumptions about not only temporal variation but also spatial variation.

Several recommendations are given. These include: 1) the need to have good statistical advice before starting an experiment, 2) the need to have a sufficient number of replicates that are spread over the range of spatial and temporal variation, and 3) the need to correctly control for serial correlation.

Key words: spatial variation, temporal, experimental design, ANOVA

Introduction

Ecological data derived from experiments and observational studies done in the field are very often variable because patterns in nature are masked by temporal and spatial variation in physical and biological factors. Even though ecologists are well aware of the problems caused by natural variation, the ecological literature is filled experiments that either ignore the difficulties caused by spatial and temporal variation or deal with them in an inappropriate manner. Here I provide an introduction to methods for controlling spatial and temporal variation. There is a vast literature in this area and I can only offer some guidelines and provide a list of helpful references.

Spatial and temporal variation can cause problems even in the most straightforward statistical tests. This can be easily seen in a simple example. Suppose we wished to test the hypothesis that grazing in the valleys that line Lake Hovsgol reduces aboveground biomass of herbaceous plants. We might test this hypothesis by setting up a simple *t*-test. The test is carried out in three steps. First, we pose the null hypothesis that the parametric means are equal (i.e. average aboveground biomass of plants is the same in grazed and ungrazed areas) and the alternative hypothesis that they are not. Next we randomly draw samples from the two populations - for example, areas where grazing animals have been excluded and areas where animal graze freely. Finally we test the hypotheses based on the magnitude of the test statistic *t*. The calculation of *t* is based on the sample sizes and sample estimates of the parametric means and variances. If we assume the two populations have the same variance and we draw samples of equal size, then $t = (\overline{Y}_1 - \overline{Y}_2)n^{1/2} / \sqrt{2}s$ where $\overline{Y}_1$ and $\overline{Y}_2$ equal the averages, n equals the sample size, and s equals the standard deviation. Failure to consider spatial and temporal variation can cause us to mis-estimate the difference between the averages, $\overline{Y}_1 - \overline{Y}_2$, and/or the standard deviation, s.

Mis-estimation arises most often when the ex-

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