Sampling for Decision Making in Crop Loss Assessment and Pest Management

Presented at the 90th Annual Meeting of The American Phytopathological Society Joint with the Entomological Society of America
November 11, 1998, Las Vegas, NV

Sampling for Decision Making in Crop Loss Assessment and Pest Management: Introduction

G. Hughes

Institute of Ecology and Resource Management, School of Agriculture, University of Edinburgh, West Mains Road, Edinburgh EH9 3JG,
Scotland, United Kingdom.

Accepted for publication 12 May 1999.

ABSTRACT

Hughes, G. 1999. Sampling for decision making in crop loss assessment and pest management: Introduction. *Phytopathology* 89:1080-1083.

Data obtained by sampling are crucial for decision making in crop loss assessment and pest management. Such data improve farmers' perceptions of the threat of pests and can, therefore, improve the quality of decision making in the practice of crop protection. The concept of a threshold, representing the dividing line between two alternative courses of action

relating to seed or crop health, is an important aspect of crop protection decision making. Sampling is the means by which the required judgment can be guided. Operating characteristic curves are an important tool in the evaluation and comparison of the performance of sampling schemes. Precision integrated pest management, in which the objective is spatially variable pest management within fields, poses new problems for decision makers and statisticians developing sampling methodology in the context of crop protection.

Norton (10) described a simple model of the crop protection decision-making process at the farm level (Fig. 1). Given a particular set of objectives, farmers must try to select an option, from among those available, that leads to a satisfactory outcome. Farmers' perceptions of pest attack and crop loss play an important part in this selection. If the outcome is unsatisfactory, farmers can seek to better the situation in the future either by means of changing their objectives, increasing their options, or improving their perceptions. To improve perceptions of pest attack and crop loss, information is required. Norton (10) listed four types of information that may contribute to an improvement in farmers' perceptions of pest attack and crop loss: fundamental information (basic biological details of pests and technical details of their management), historical information (records of previous levels of pest attack and any indicated trends), real-time information (records of current pest status collected by means of monitoring schemes), and forecast information (predictions of future levels of pest attack and crop loss). Because all except the first of these are dependent, at least to some extent, on data obtained by sampling, it is clear that sampling has a crucial role to play in improving farmers' perceptions of the threat of pests and, therefore, in improving the quality of decision making in the practice of crop protection. The papers presented at the symposium "Sampling for Decision Making in Crop Loss Assessment and Pest Management," sponsored by the Plant Disease Losses Committee of The American Phytopathological Society (APS) and the Crop Protection Section of the Entomological Society of America (ESA) and held at the joint APS/ESA meeting in Las Vegas

from 8 to 12 November 1998, all dealt with aspects of sampling in the context of crop protection decision making.

Sampling takes time, costs money, and provides information that is subject to uncertainty. In crop protection decision making, we are faced with the need for timely detection of pests and patho-

Fig. 1. A model of crop protection decision making. (Reproduced, by permission, from Norton [10]; copyright British Crop Protection Council)

Corresponding author: G. Hughes; E-mail address: ghughes@srv0.bio.ed.ac.uk

Publication no. P-1999-0907-02O

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gens, or the injuries they cause, often at low frequencies. Furthermore, many populations of harmful organisms have heterogeneous spatial patterns in the field. These factors often mean that simple calculations of the sample sizes required to estimate pest populations with a prespecified level of confidence result either in unrealistically large required sample sizes (if a typically low level of uncertainty is specified) or unhelpfully high levels of uncertainty (if a typically low budget is allocated to sampling). Thus, efficient use of resources devoted to sampling was a common theme of the symposium. Morrison (9) discusses sampling in seed health testing, in which appropriate sampling procedures have been developed by seed testing organizations such as the International Seed Testing Association and the Association of Official Seed Analysts. Sampling procedures for assessing pests and pathogens in the field have developed more on a case-by-case basis. Until recently, little research in plant pathology has been devoted to sampling methods appropriate for assessing disease incidence and severity. In contrast, economic entomology has seen a large amount of effort devoted to sampling methods for assessing pest population density, with particular emphasis on sequential sampling.

Both in sampling for seed health testing and in sampling for pests and pathogens in the field, the concept of a threshold is important. In its simplest—and most frequently encountered—form, we have a discrete choice threshold, representing the dividing line between two alternative courses of action relating to seed or crop health. One action is taken if the population in question is judged to be above the adopted threshold, the other is taken if the population is judged to be at or below the threshold. This may involve, for example, the decision to reject or accept a seed lot or the decision to implement or withhold crop protection measures. Sampling is the means by which the required judgment can be guided.

Decision making will be imperfect whatever the sampling scheme. Along with correct decisions to act when action is required (true positives) and not to act when action is not required (true negatives), incorrect decisions will sometimes be reached. That is to say, sometimes the decision to act will be made when action is not required (false positives), and sometimes the decision not to act will be made when action is required (false negatives). Operating characteristic (OC) curves are instrumental in establishing and evaluating the performance of sampling schemes.

The following example demonstrates the use of OC curves. The example is based on a hierarchical sampling scheme for assessing in-

cidence of citrus tristeza virus (CTV) infection (3). A decision threshold of 10% CTV-positive trees was adopted ($t_{low} = 0.1$). Exceeding this threshold incidence is the signal for implementation of a census of the grove in question in order to identify and remove infected trees. In this example, the quadrat, rather than the individual tree, is the sampling unit; N quadrats, each of $n = 4$ trees, are sampled. The threshold on the quadrat scale is $t_{high} = 1 - (1 - t_{low})^n$. The largest integer less than or equal to $t_{high} \cdot N$ is denoted T_{high} . Thus, T_{high} is the largest number of quadrats with at least one CTV-positive tree, out of a total of N quadrats, that can be observed without t_{high} being exceeded. The OC curve then shows the probability that the observed number of quadrats with at least one CTV-positive tree (X) is less than or equal to T_{high}

$$\Pr(X \leq T_{high}) = \sum_{x=0}^{T_{high}} \Pr(X = x)$$

in which $\Pr(X = x)$ is based on the binomial distribution. This represents a sampling likelihood: the probability of a decision (correct or otherwise) that the incidence of CTV-positive trees is less than or equal to the adopted threshold (at the individual tree scale) of 10%, for any actual value of incidence at that scale.

Fig. 2. An example of an operating characteristic (OC) curve from a study of sampling for citrus tristeza virus (CTV) incidence (3). The adopted decision threshold of 10% CTV-positive trees ($t_{low} = 0.1$) is shown as a vertical dashed line. The OC curve for the CTV sampling scheme outlined in the text is the curve describing the true negative proportion (TNP) and the false negative proportion (FNP). Also shown is the curve describing the false positive proportion (FPP) and the true positive proportion (TPP). The curve describing FPP and FNP (shown as a solid line) represents the probability of misclassification for the sampling scheme described.

Fig. 3. Disease progress curves for combined incidence of tobacco etch and tobacco vein mottling virus disease in tobacco fields in Kentucky (7,8). The time axis shows days after first appearance of symptoms of virus infection. **A**, Disease incidence is the proportion of diseased plants, based on a total number of 3,000 plants. **B**, The field was divided into 75 quadrats, each containing 40 plants. Disease incidence is the number of diseased plants per quadrat. Disease progress is shown separately for each quadrat. (Reproduced, by permission, from Hughes et al. [5]; copyright Oxford University Press)

Up to and including the adopted threshold of 0.1 (10% CTV-positive trees), the OC curve shows the true negative proportion (TNP), representing the probability of deciding that a sampled block of citrus has an incidence less than or equal to the threshold, given that the actual incidence is less than or equal to the threshold. Above the adopted threshold of 0.1 (10% CTV-positive trees), the OC curves show the false negative proportion (FNP), representing the probability of deciding that a sampled block has an incidence less than or equal to the threshold, given that the actual incidence is greater than the threshold. The OC curve for the CTV sampling scheme outlined here is the curve describing TNP and FNP in Figure 2. We can also define the false positive proportion (FPP = 1 – TNP) and the true positive proportion (TPP = 1 – FNP). By plotting both the OC curve and the curve describing FPP and TPP on the same axes (Fig. 2), we can characterize the probability of misclassification associated with the sampling scheme. This is represented by FPP (below the threshold) and by FNP (above the threshold). Note that this probability is highest close to the adopted threshold. Madden and Hughes (6) show how OC curves are affected by the sampling distribution of pathogen intensity and by sample size.

When sampling is used to decide whether or not to take action, based on an indication of unacceptable levels of economic loss in the future, the threshold is the critical level of the adopted indicator variable. The implications of a poorly specified threshold are discussed by Nyrop et al. (11). In such cases, aspects of ‘case-control’ methodology, as used in clinical studies, may help answer questions about the choice of an appropriate threshold level (4,14).

Implicit in the preceding discussion is an assumption that crop protection is practiced on a whole-field scale. Sampling produces an estimate of pest or pathogen population density, or of disease incidence or severity, and action is or is not taken after comparison of this estimate (often a mean) with the adopted threshold value. However, pest and pathogen populations are rarely spatially homogeneous. For example, Figure 3 shows data from a sequence of assessments of incidence of two aphid-transmitted virus diseases

(7,8). Tobacco fields were divided into 75 sampling units (quadrats), each containing 40 plants. In Figure 3A, the disease progress curve shows the increase in mean incidence on a whole-field basis, based on a total of 3,000 plants scored for the presence or absence of disease symptoms at each of a series of assessments in one field. In Figure 3B, disease progress in the same field is shown separately for each of the 75 quadrats. It is clear that, even though all quadrats were treated the same, disease incidence varied spatially as well as temporally.

Stern et al. (13) pointed out the implications of such spatial heterogeneity for a threshold approach to crop protection decision making (Fig. 4). Even at high mean pest population levels, some areas are below the threshold because of local fluctuations in pest population density. Conversely, at low mean pest population levels, some areas are above the threshold because of local fluctuations in population density. One way to take into account spatial heterogeneity of pests and pathogens is to use individual sample values as input to nonlinear crop loss assessment models and calculate the resulting mean loss (2). However, this still represents a whole-field approach, taking no account of the spatial location of areas of high and low pest or pathogen population density. Fleischer et al. (1) deal with spatially variable pest management within fields. In precision integrated pest management (IPM), the objective of sampling is to measure spatial variation and map pest density or pressure. Some interesting contrasts between sampling for whole-field crop protection and sampling in precision IPM are highlighted.

The symposium papers that follow represent the state of the art. They also indicate that many research challenges remain for those involved in decision making in crop loss assessment and pest management. The requirement for accuracy and precision in data relating to pest management and crop loss assessment continues. The long and often symbiotic association between crop protection decision making and applied statistics (12) that has provided the basis for many developments in sampling methodology will need to continue into the future.

Fig. 4. Schematic graph of the population trend and population dispersion of a pest species over a long period of time. A solid line depicts the fluctuations in population density with time. The broken line depicts the general equilibrium position. The population dispersion is indicated at the specific times A, B, and C. The basal area of these models reflects the distributional range, and the height represents population density. Population densities above the economic threshold are in black. (Reproduced, by permission, from Stern et al. [13]; copyright Regents of the University of California)

ACKNOWLEDGMENTS

I thank G. A. Norton and the British Crop Protection Council for permission to reproduce Figure 1; the Institute of Mathematics and Its Applications and Oxford University Press for permission to reproduce Figure 3; and V. M. Stern and the University of California Division of Agriculture and Natural Resources for permission to reproduce Figure 4.

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