IOBC / WPRS

**Working Group "Integrated Control in Glasshouses"**

OILB / SROP

**Groupe de Travail "Lutte Intégrée en Cultures sous Verre"**

Origineel

# CONTRIBUTIONS WORKING GROUP MEETING

at

**Vienna (Austria)**
**20 - 25 May 1996**

Edited by J.C. van Lenteren

IOBC wprs Bulletin
Bulletin OILB srop Vol. 19 (1) 1996

# Methodology for developing and evaluating monitoring programs for crop pests and diseases

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## ABSTRACT

Monitoring of pests or diseases over time is often required to schedule interventions (biological, chemical or other) at the right time. To minimize sampling effort in monitoring programs, risks of overtime detection of damaging outbreaks must be balanced against the labour costs of intensive monitoring. This paper advocates a structured approach to designing monitoring programs. Computer simulation of sampling over time, pest population dynamics, and pest damage is used to evaluate options for monitoring programs. The best monitoring program in the simulations is tested in the field. This approach has worked well for developing an optimal monitoring program for European red mite in apples. The methodology is applicable in many other crop-pest systems.

Many important pests (e.g. mites, aphids, trips) and diseases (rusts, mildews, Botrytis spp.) have multiple generations per year and pose a risk of outbreak over an extended period of time. Whether and when intervention is necessary depends on driving variables such as weather and natural antagonists, and is difficult to predict. Monitoring (i.e. sampling over time) is therefore often required. Several approaches have been developed to schedule sampling over a pest or disease season (Zadoks, 1989; Nyrop et al., 1994; Pedigo, 1994; Wilson, 1994), but compared to the vast body of theory and practical approaches on pest sampling (Pedigo & Buntin, 1994), the development of monitoring methods is in its infancy. Little work on monitoring theory has been done, despite the practical relevance of monitoring and the potentially large benefits of optimizing the methods that are currently used.

Nyrop et al. (1994) formulated a methodology for developing and evaluating monitoring methods which comprises five steps (Fig. 1). They distinguish between sampling plans, which are defined as procedures used to estimate or classify density, and monitoring protocols, which are defined as the way in which sampling plans are used to track density through time.

1. Construction of a set sampling plans that are used to determine whether intervention is necessary or not. If no intervention is necessary, the time at which the pest should be resampled is indicated. For red spider mite in apples (*Panonychus ulmi* Koch), Nyrop et al. (1994) used sampling schemes that decided between immediate intervention, resampling after one week and resampling after two weeks (Fig. 2).
2. Monte Carlo simulation of the performance of each of the sampling plans in terms of 1) the probability of taking one of the possible decisions, and 2) the average number of sample units required to make a decision (Fig. 3). These two criteria are functions of the true pest density only, assuming that the variance of population density is a function of the mean density. Nyrop et al. (1994) represented the sampling distribution of red spider mites over leaves with a negative binomial distribution, using a power relationship between the variance and the mean to calculate the dispersion parameter $k$.

3. Calculation of the performance of a chain of sampling plans used over a season to monitor density through time. Performance is calculated by combining the performance criteria of the sampling plans (functions of density) with simulated or observed trajectories of density over time. The performance of a monitoring protocol for a given set of population trajectories is characterized by five criteria:
   - the probability of intervening
   - the cumulative pest density up till the moment of intervention
   - the density at the moment of intervention
   - the total number of sampling bouts scheduled
   - the total number of samples taken in all bouts.

   An example of simulated performance is given in Fig. 4. The overall performance depends on the performance of each of the sampling schemes for given densities and on the population trajectorie(s). Schemes that have good performance for slowly growing pest populations (biological control!) might have bad performance for rapidly growing populations, and vice versa (Binns et al., in press).
4. Next, the parameters of sampling plans constituting the monitoring protocol are varied, in order to identify the set of sampling plans that gives the most desirable performance. Thereby, the performance criteria are weighted by expert judgement.
5. The best monitoring protocol resulting from the iterative simulation process is tested in the field. If its favourable performance is confirmed, it can be extended to practice. The monitoring scheme developed by Nyrop et al. (1994) is currently recommended to and used by New York apple growers and field scouts (Wilcox et al., 1995).

This procedure of developing and analysing the performance of monitoring protocols by simulating sampling and population dynamical processes provides two advantages. The first is that insight is gained in the relationship between parameters of sampling plans and the performance of monitoring protocols. The second advantage is that aspects of sampling methods that give good performance in the monitoring context may be deliberately sought, and optimized. For instance, Nyrop et al. detected by their simulations that the intervention thresholds for red spider mite that were used in practice, were more risk averse (had a tendency towards intervening) than was thought. It was also found that monitoring protocols consisting of low precision sampling plans with raised thresholds (to avoid unnecessary intervention) gave as good protection against population outbreaks as high precision plans, but with much less sampling effort. In the future, thresholds may be raised on the basis of these findings. This will improve the chances for biological control.

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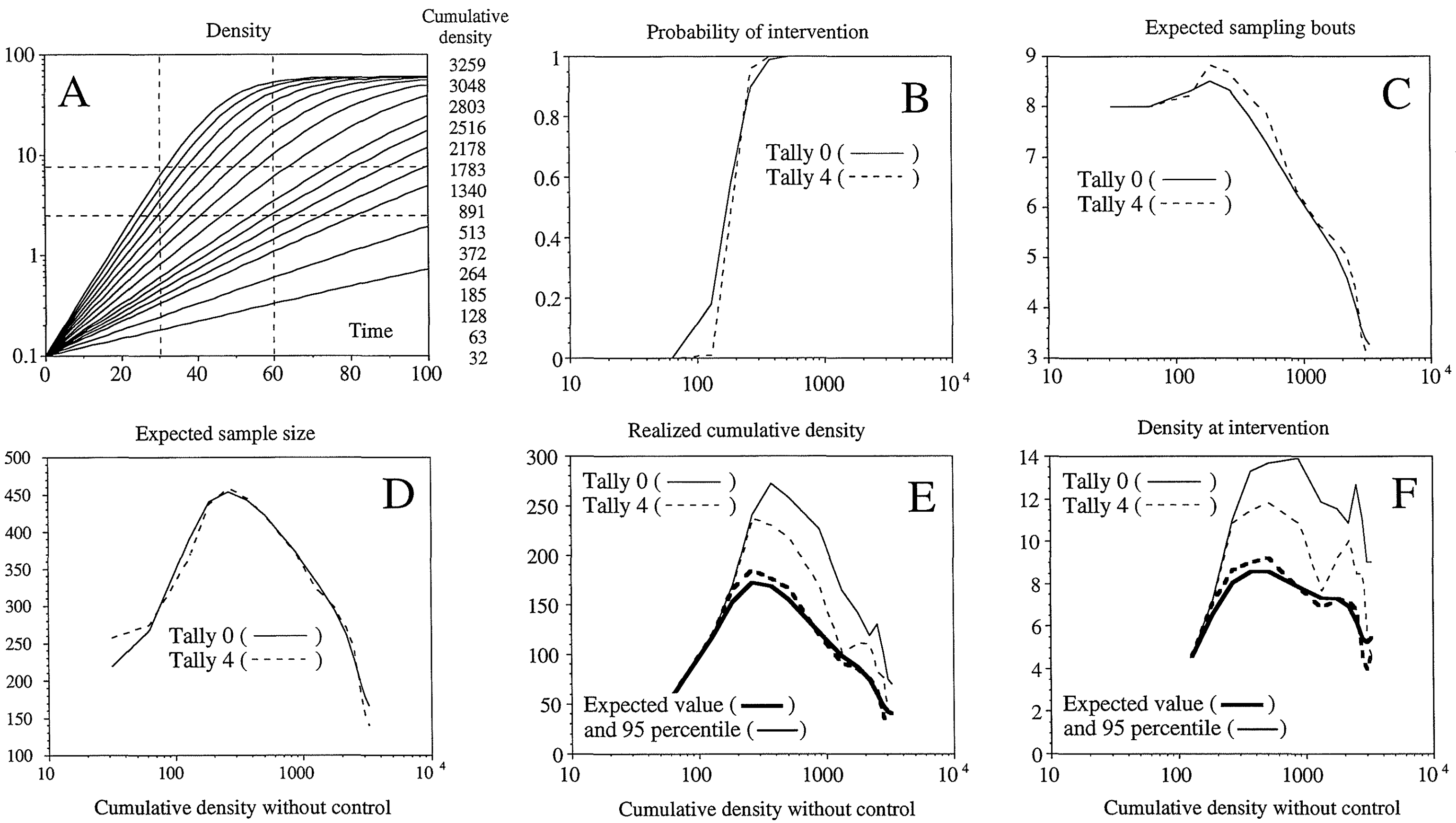


Fig. 4: Simulated performance characteristics of two monitoring protocols, based on tripartite presence/absence classification, when monitoring mite populations over a period of 90 days. The comparison is made using logistic population trajectories with a maximum level of 50 mites/leaf and differing relative growth rates (A). Both protocols are based on critical densities of 2.5, 5 and 7.5. mites/leaf over the time periods 0-30, 31-60 and 61-90 days. Protocol 1 (**drawn lines**) is based on simple presence/absence monitoring (**tally 0**). Protocol 2 (**hatched lines**) is based on counting leaves with more than 4 mites/leaf (**tally 4**), which yields a more precise relationship between incidence and density, but is more laborious to execute in the field. The performance criteria are: (B) the probability of intervention, (C) the expected number of sampling bouts, (D) The expected total number of sample units, (E) the accumulated number of mite-days per leaf, and (F) mite density at the time of scheduled intervention. Performance criteria are quite similar for the two protocols, except for the 95th percentiles of density at intervention and cumulative mite density. These measures for 'risk' are higher for the less accurate presence/absence based monitoring method. Curves for the 95 percentiles are jagged due to the stochastic nature of the simulations.

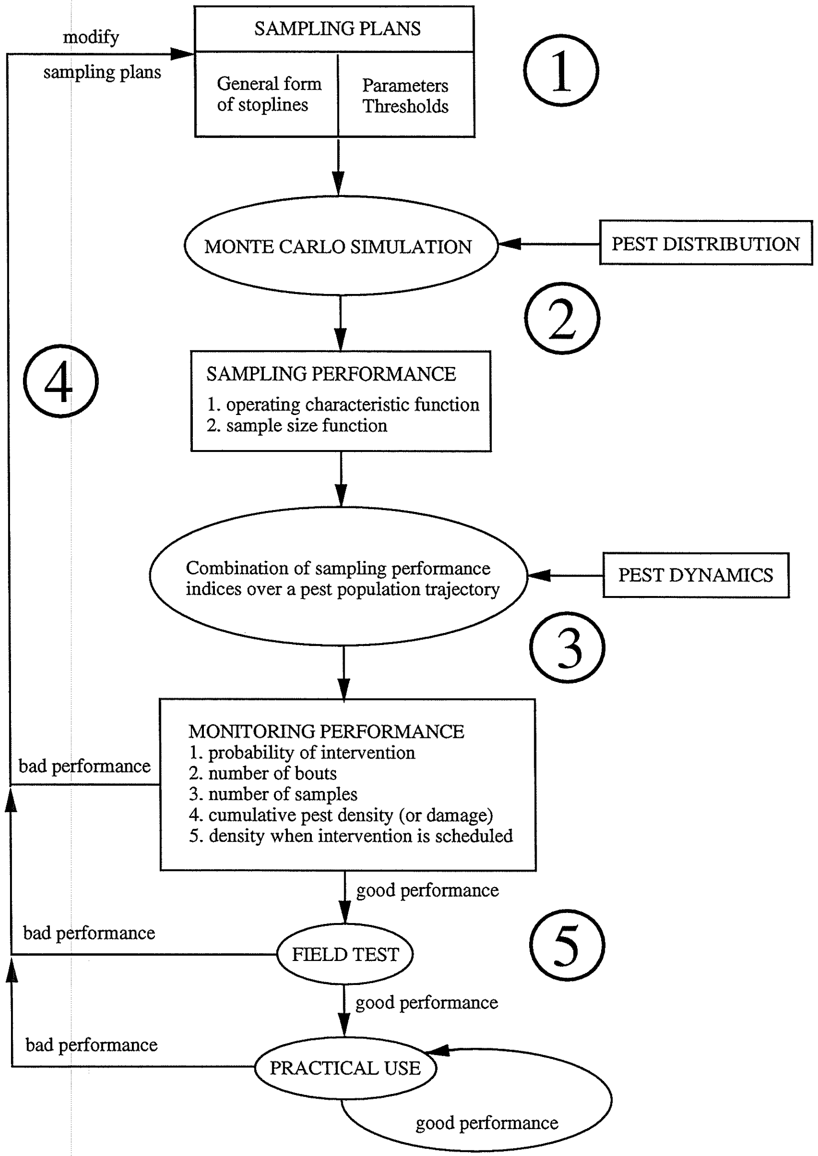


Fig. 1: five steps in developing and evaluating a monitoring protocol

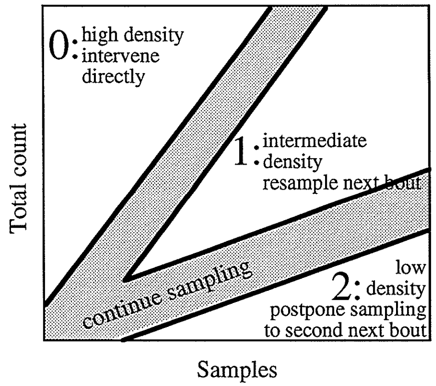


Fig. 2: Protocol for tripartite sequential classification. Leaves are inspected one by one. The cumulative number of 'positive' leaves (vertical axis) is plotted against the running total number of inspected leaves. As long as the point indicating the result of sampling is in the grey areas, sampling has to be continued. As soon as the point moves into one of the three white areas, the result of sampling is reliable enough to take a decision. The decisions are intervene (0), resample at next occasion (1), and resample at second next occasion (2).

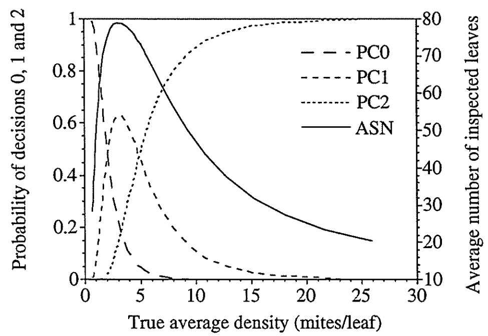


Fig. 3: Performance characteristics of a tripartite sequential classification sampling plan.
Left axis: **P**robability of making one of three alternative **C**lassifications:
PC0 – – - intervene,
PC1 ----- resample at next occasion, and
PC2 ········ resample at second next occasion.
Right axis: ASN = average number of leaves (——) inspected before taking a decision